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SKYLAB PROGRAM
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Technical Report

Skylab Interior Acoustic Environment Report

(Preliminary)

Contract NAS8-24000

50217

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FOREWORD

This document is submitted in accordance with the requirements of Technical Reports, Line Item No. 8 of Data Requirements List, Annex I to Exhibit A, Statement of Work Payload Integration of Contract NAS8-24000.

This report is in response to PL 2082, Volume I Rev D, Work Breakdown Structure No. 1311 Document Sequence No. 62, Item 4a, Skylab Interior Acoustic Environment Report.

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1. SCOPE

1.1 Purpose - This report presents a description of the work performed and the results obtained under WBS/Task No. 1311-62, SWS Subsystem Interior Acoustic Levels - Orbital Conditions, during the time period from 1 December 1971 to 29 February 1972.

1.2 Scope - This report updates, where applicable, the task objectives, identification and location of noise sources, mapping of the acoustical environment, and potential problem areas which were presented in the previous report.

1.3 Summary - Equipment and experiments have been reviewed and updated for applicable noise sources. The available acoustic data from these noise sources are presented and, where sufficient information was available, have been converted to estimated sound pressure levels in the Skylab Interior.

Skylab Interior acoustical noise limits which are considered acceptable for continuous exposure have been established by the Medical Research and Operations Directorate. The estimated sound pressure levels (SPL's) for the Skylab Interior have been compared to the acoustical noise limits to allow a determination of which noise sources may produce SPL's which presently exceed the noise limits.

In addition to individual noise sources, analyses were performed to determine the effects of additive acoustic levels at applicable crew work stations and rest stations. Comparisons of the data are presented in several forms, primarily as octave band SPL's versus frequency and in terms of Speech Interference Levels (SIL's).

Conclusions and recommendations based on the results of this report are included, and potential problem areas are identified.

2. APPLICABLE DOCUMENTS

The following documents, of exact issue shown, are applicable to the extent specified herein.

PROJECT DOCUMENTS

Contractor

ED-2002-1055	Technical Report, Preliminary Saturn Workshop (SWS) Acoustical Environmental Mapping, Martin Marietta Corporation, Denver, Colorado, 1 July 1970.
ED-2002-1200-1	Technical Report, Skylab Interior Acoustic Environment Report, Martin Marietta Corporation, Denver, Colorado, 30 October 1970.
ED-2002-1200-2	Technical Report, Skylab Interior Acoustic Environment Report, Martin Marietta Corporation, Denver, Colorado, 31 January 1971.
ED-2002-1200-3	Technical Report, Skylab Interior Acoustic Environment Report, Martin Marietta Corporation, Denver, Colorado, 30 April 1971.
ED-2002-1200-4	Technical Report, Skylab Interior Acoustic Environment Report, Martin Marietta Corporation, Denver, Colorado, 31 July 1971.
ED-2002-1200-5	Technical Report, Skylab Interior Acoustic Environment Report, Martin Marietta Corporation, Denver, Colorado, 30 November 1971.

3. TASK DESCRIPTION

3.1 Task Objectives - The primary task objective is to coordinate with NASA/MSFC and equipment contractors to assure compliance with the requirements established by the Medical Research and Operations Directorate. To achieve the primary objective, the following tasks are being performed and the results, where applicable, are included in this report.

3.1.1 Identify and locate noise sources applicable to the Saturn Workshop (SWS) orbital configuration. Determine the frequency of use and duration of operation of noise sources as a function of mission profile time. Maintain and update maps of the acoustic environment for the Skylab interior based on currently available data in order to identify potential problem areas.

3.1.2 Coordinate with Marshall Space Flight Center (MSFC), Manned Spacecraft Center (MSC), and equipment contractors to establish test methods, measurement requirements, locations, and time/line schedules for obtaining noise level measurements during the Skylab mission.

3.1.3 Update analyses as required to evaluate the effects of additive noise sources at crew work stations and rest stations. These analyses shall reflect nominal continuous levels and maximum levels resulting from equipment/experiment operation during the mission profile.

3.1.4 Participate in test planning and measurement requirements for IMC and Post Landing Ventilation (PLV) fans to be tested at MSFC and McDonnell Douglas Company-Eastern Division (MDAC-E). Analyze data and determine the suitability of use of IMC fans considered for use as backup units for the PLV fans. Evaluate the effect of IMC fan acoustical characteristics on the Skylab interior noise environment.

3.1.5 Coordinate with MSFC and MDAC-E to establish test plans and measurement requirements for noise system verification tests to be conducted during the System Acceptance Tests (SAT) of the Airlock Module/Structural Transition Section/Multiple Docking Adapter (AM/STS/MDA) at 14.7 psia in the MDAC-E vacuum chamber. Monitor tests, analyze reduced data, and correlate results with Skylab interior noise environments.

3.1.6 Monitor tests and perform analyses of acoustic data from equipment items operating inside the U1 (first AM/STS flight article) during the SAT at 5.0 psia. Compute the additive effects of equipment items operating during the test and other Skylab noise sources. Correlate test results with interior noise level criteria.

3.1.7 Review and evaluate the results of the Audiological Annoyance Syndrome Study for Skylab performed by Stanford Research Institute (SRI). Correlate results with the Skylab interior noise environment.

3.1.8 Coordinate with MSFC and MSC in defining acoustic measurement requirements during the Skylab Medical Experiment Altitude Test (SMEAT) at MSC. Monitor tests and correlate noise levels and crew annoyance and/or communications problems with the SRI study (see para. 3.1.7) and the Skylab acoustical environment and mission profile.

3.1.9 Review and correlate results of acoustic measurements from subsystem tests in the Orbital Workshop at McDonnell Douglas Astronautics Company-Western Division (MDAC-W).

3.1.10 Analyze interior noise level measurements obtained during the mission and correlate results with predicted levels.

3.2 Skylab Acoustic Criteria - Acoustic criteria have been established applicable to both sound pressure levels (SPL's) and sound power levels (PWL's). These criteria have been described in reference 1 and are repeated in the following paragraphs.

3.2.1 Acoustical Noise Criteria - The noise limits for continuous exposure which have been established by the Medical Research and Operations Directorate are indicated in figure 1. This figure is repeated from the interim report dated July 1, 1970 (see reference 1) in order to incorporate all pertinent current data in a single document. These levels are applicable for any noise source or combinations of noise sources operating continuously during orbital conditions. In order to ensure that the additive effects due to combinations of noise sources do not exceed these levels, the levels specified in figure 1 are applicable to individual items of equipment operating at standard atmospheric conditions (14.7 psi and 68°F). (For comparison purposes, figure 1 levels are indicated in some of the figures, together with data applicable to a 5.0 psi atmosphere).

3.2.2 Fan/Muffler Sound Power Level Criteria - A revised sound power level (PWL) has recently been issued (see reference 3). This document revises previous PWL criteria applicable to MDA Fan/Muffler assemblies, which had been described in reference 3. A comparison of the revised criteria and the original criteria are indicated in figure 2. A comparison of the resulting MDA SPL's from these PWL criteria was described in paragraph 3.3.2 of reference 1.

3.3 Noise Sources - Acoustic data applicable to individual noise sources have been well documented in previous reports (see references 1, 2, 4, 5, and 6). This section summarizes and updates, where applicable, these data.

The data are presented in terms of noise sources associated with either the AM/STS, MDA, or the OWS.

3.3.1 Airlock Module/Structural Transition Section - Acoustic data applicable to the AM/STS have been described and presented in reference 1. Modifications to these data are presented in this section.

3.3.1.1 OWS Cooling Module Fan/Muffler - This noise source is located in the AM and is treated as a continuous noise source. The estimated octave band sound pressure levels (O.B. SPL's) in the AM/STS due to this noise source are indicated in figure 3. Figure 3 reflects an update to figure 12 in reference 1 and is due to the incorrect inclusion of pressure effects in the 125 and 250 hertz octave bands at 5.0 psia. These corrections have also been applied to the Teleprinter and Cabin Heat Exchanger Fan/Muffler SPL's in the 125 and 250 hertz octave bands. These corrections are applicable only to the AM/STS SPL's presented in this report.

3.3.1.2 Teleprinter - This noise source is located in the Structural Transition Section (STS). It is an intermittent noise source, however it may be activated during astronaut sleep periods. The estimated O.B. SPL's in the AM/STS due to this noise source have been updated from figure 6, of reference 1, and the results are indicated in figure 4. Additional updates to the acoustic data shall be incorporated upon completion of modifications presently being performed by MDAC-E.

3.3.1.3 Cabin Heat Exchanger Fan/Muffler - This noise source is located in the STS and is considered to be a continuous noise source. Estimated O.B. SPL's in the AM/STS due to this noise source are indicated in figure 5, which is an update to figure 8 of reference 1.

3.3.1.4 OWS Interconnect Duct Fan/Muffler - This noise source is located at the AM/STS interface and is considered to be a continuous noise source. Estimated O.B. SPL's in the AM/STS due to this noise source are indicated in figure 6, which is an update to figure 10 of reference 1. Included in figure 6 are the estimated O.B. SPL's utilizing the experimental PWL obtained recently from MDAC-E. These PWL data are indicated in Table I. No updated PWL data applicable to a 14.7 psia atmospheric pressure are presently available.

3.3.1.5 Condensing Heat Exchanger - This noise source is located in the STS. Estimated O.B. SPL's in the AM/STS applicable to this noise source are indicated in figure 7, which is an update to figure 14 of reference 1. Included in figure 7 are the estimated O.B. SPL's utilizing the experimental PWL obtained recently from MDAC-E. These PWL data are indicated in Table I. These experimental PWL's were obtained by MDAC-E after several modifications had been made, the primary one being incorporation of isolators in the suit compressor installation to reduce metal to metal contact. No updated PWL data applicable to a 14.7 psia atmospheric pressure are presently available.

The acoustic data for this noise source, described in figure 7 of this report and figure 14 of reference 1, are applicable to one compressor in one module. Since during normal operations one compressor in each module (unit) will be performing a baking function while the other compressor in the other module will be performing a cooling and condensing function, the acoustic data referred to above should be increased by three decibels to include operation of two compressors simultaneously. The remaining two compressors (one in each module) are expected to operate as backups.

The Condensing Heat Exchanger has been considered as an intermittent noise source in this and previous reports. Recent information, however, indicates that the compressors operate continuously, which would cause this to be a continuous noise source.

3.3.2 Multiple Docking Adapter - Acoustic data applicable to the Multiple Docking Adapter (MDA) have been previously described in references 2, 4, and 6. The only significant noise sources located in the MDA, and analyzed to date, have been the three Fan/Muffler Assemblies.

Experiment S009, a Nuclear Emission experiment, is also located in the MDA and had previously been identified as a noise source which had been quieted considerably by the replacement of metal gears by LEXAN gears (LEXAN is a type of plastic having properties similar to nylon). It has recently been questioned, however, whether adequate noise reduction was obtained by replacement of the gears. Acoustic data has been requested in order to adequately define S009 noise characteristics.

3.3.3 Orbital Workshop - A total of twelve noise sources have been identified in the OWS. Six of these noise sources are directly applicable to the OWS, while six are experiments operated or located in the OWS. The six noise sources directly applicable to the OWS are described as follows:

a. Three Ventilation Control System (VCS) Fan Clusters: Three specific sources constitute the VCS noise source, which is treated in the analyses as a continuous noise source.

b. Refrigeration System: This item is treated as a continuous noise source.

c. Odor Fan: This item was refered to in previous reports (see references 4 and 6) as the Waste Management Blower. It is treated as an intermittent noise source.

d. Fecal Collector: This item is treated as an intermittent noise source and consists of two distinct noise sources, described as follows:

   1) Collector Power Module Output,

   2) Centrifugal Urine Separator.

e. Three Portable Fans: The portable fans are treated as intermittent sources, although the possibility exists that they may be operated continuously.

f. Suit Drying Station: This item is treated as an intermittent noise source.

No new data or information has been obtained applicable to items (a) through (f). PWL's and estimated SPL's for these noise sources are described in reference 1.

3.3.3.1 OWS Experiment Noise Sources - In addition to the six noise sources from equipment items located in the OWS, six experiments also located in the OWS have been identified as intermittent noise sources. The noise sources are described as follows:

a. M509 Thrusters,

b. T020 Nozzles,

c. M171 Ergometer,

d. M074 Specimen Mass Measurements,

e. M172 Body Mass Measurements,

f. M131 Revolving Chair.

3.3.3.1.1 M509 Thrusters and T020 Nozzles - The PWL's and SPL's applicable to the M509 Thrusters and the T020 Nozzles are indicated in Table III and figures 35 and 36 of reference 1. For the M509 Thrusters, SPL's were estimated for two possible operating conditions. The first condition consisted of one nozzle operating at 4.3 pounds thrust and the other condition consisted of a combination of nozzles yielding a maximum thrust of 15.8 pounds.

The T020 SPL's were also calculated for two operating conditions, one nozzle operating (one pound of thrust) and four nozzles operating (four pounds of thrust).

3.3.3.1.2 M171 Ergometer - The M171 Ergometer acoustic analyses presented in reference 1 were based on PWL data obtained from OWS Mockup Tests (see references 2 and 4). During Ergometer operation SPL measurements had been obtained from a microphone located at the operator's ear. Equation (1) was used to estimate the PWL's applicable to the Ergometer.

$$PWL = SPL + 10 \log_{10} V - 10 \log_{10} (P/P_{ref}) - 10 \log_{10} T_{60} - 19.6 \text{ dB}, \quad (1)$$

where V = internal volume of the enclosure, in cubic feet,

P = ambient pressure in the enclosure, in psia,

P_{ref} = reference ambient pressure = 14.7 psia,

T_{60} = reverberation time, at either 14.7 or 5.0 psia.

Equation (1) is only applicable for reverberant sound energy effects, however, since it assumes direct energy effects to be negligible. A further study of the Ergometer test data described above indicates that, due to the close proximity of the microphone to the noise source (approximately three feet), direct sound energy effects are indeed significant. The expression incorporating both direct and reverberant effects is indicated as follows:

$$PWL = SPL - 10 \log_{10} \left\{ \frac{1}{4\pi r^2} + \frac{4}{R} \right\} - 0.5 \text{ dB} \tag{2}$$

(see reference 7)

where r = distance from the center of the noise source to the microphone, in feet,

R = room constant, in square feet.

The resulting Erogometer PWL's using equation (2) rather than equation (1) are indicated in Table II. The original PWL's utilizing equation (1) are also included for comparison purposes.

SPL's in the OWS due to operation of the Ergometer were calculated using the PWL's obtained from equation (2) in equation (3), indicated as follows:

$$SPL = PWL - 10 \log_{10} V + 10 \log_{10} (P/P_{ref}) + 10 \log_{10} T_{60} + 19.6 \text{ dB}. \tag{3}$$

The resulting SPL's are indicated in figures 8 and 9.

3.3.3.1.3 <u>M074 and M172 Body Mass Measurements</u> - The M074 Specimen Mass Measurements and M172 Body Mass Measurement experiments have been identified as intermittent noise sources. The experiments include an electronic counter which emits a high frequency noise. The only acoustic data presently available are two A-weighted measurements obtained from a sound level meter. These measurements are applicable to a flight unit electric counter and indicate a maximum of 88 dBA in the immediate vicinity of the counter and approximately 80 dBA in the area of the crewman's head for the M172 experiment. No additional acoustic measurements are presently scheduled to be obtained.

3.3.3.1.4 <u>M131 Revolving Chair</u> - The M131 Revolving Chair experiment is expected to be an intermittent noise source. No acoustic data or estimates of the PWL's associated with this experiment are presently available.

3.4 Composite Noise Source Acoustics - Corrected sound pressure levels for applicable sections of the Skylab configuration due to operation of the OWS Interconnect Duct Fan, Condensing Heat Exchanger and the Ergometer are presented in this section. SPL's for each receiving space due to operation of the other Skylab noise sources are not discussed in this report, due to their inclusion in reference 1. Since the Interconnect Duct Fan is a continuous noise source, the revised composite SPL's due to operation of continuous noise sources are also presented for each section.

In order to represent the Skylab interior acoustic environment in a more realistic manner than by using the AM/STS and MDA contractor divisions, the MDA and STS have been combined as one acoustical space and the AM as a separate acoustical space. The reasons for these changes are discussed in further detail in reference 1.

The following paragraphs describe the method used to calculate the SPL's in each section due to these individual and composite noise sources. SPL's (both individual and composite) are presented in figures 10 through 22.

3.4.1 Multiple Docking Adaptor/Structural Transition Section (MDA/STS) - Since the acoustical spaces used in this analysis have been redefined from the MDA and AM/STS to the AM and MDA/STS sections, the resulting SPL's in the MDA/STS will be different from the SPL's in the AM/STS. The following paragraphs describe these differences for the updated noise source.

3.4.1.1 MDA/STS SPL's Due to AM/STS Noise Sources - Sound pressure levels in the MDA/STS due to the Interconnect Duct Fan and Condensing Heat Exchanger were estimated using equation 3 and the appropriate MDA/STS room constants. The resulting SPL's, due to operation of the OWS Interconnect Duct Fan, are indicated in figure 10 for a 5.0 psia ambient pressure. Both the updated and originally estimated SPL's are shown. It can be seen that the SPL's do not exceed the Skylab Interior Noise Criteria. Figure 11 indicates the original and revised SPL estimates in the MDA/STS due to operation of the Condensing Heat Exchanger at 5.0 psia. The revised SPL's do not exceed the noise criteria, whereas the previously estimated SPL's did exceed the criteria by a significant margin above 1000 hertz.

3.4.1.2 MDA/STS SPL's Due to OWS Noise Source - To obtain an estimate of the sound pressure levels in the MDA/STS due to noise sources located in the OWS, the following expression, described in reference 1 was applied:

$$PWL_2 = PWL_1 + 10 \log_{10}\left(\frac{Sw}{R_1}\right) - TL \tag{4}$$

where PWL_1 = noise source PWL located in room 1,

PWL_2 = PWL of noise source applicable to room 2,

Sw = area of common wall between rooms 1 and 2,

R_1 = room constant of room 1 = $S\bar{\alpha}/(1-\bar{\alpha}) \cong .049V_1/T_{60}$,

TL = transmission loss of common wall = 0 for an open passage,

$\bar{\alpha}$ = absorption coefficient.

Combining equations (4) and (1) yields the PWL of the noise source applicable to room 2 in terms of the SPL in room 1:

$$PWL_2 = SPL_1 + 10 \log_{10} \frac{Sw}{4} - 10 \log_{10}\left(\frac{P}{P_{ref}}\right) - TL. \tag{5}$$

The surface area of the passage between the AM and STS is 23 ft^2 and the area between the AM and OWS is 8.9 ft^2.

Equations 5 and 3 were then used to estimate the SPL in the MDA/STS due to the Ergometer, located in the OWS. The resulting SPL's are presented in figures 12 and 13 for 14.7 psia and 5.0 psia, respectively. At 14.7 psia, the estimated SPL's exceed the Skylab Interior Noise Criteria in the 250, 500 and 1000 hertz octave bands, while at 5.0 psia the SPLs exceed the criteria by less than one decibel in the 1000 hertz octave band. It should be noted that the Ergometer is an intermittant noise source, and the criteria is applicable to continuous noise sources.

3.4.1.3 MDA/STS Composite SPL's Due to Continuous Noise Sources - The Interconnect Duct Fan is presently the only continuous noise source with power levels updated from reference 1. Thus the resulting composite SPL's due to continuous noise sources have changed only slightly from the SPL's given in reference 1. Figure 14 indicates the SPL's due to the OWS, AM, and MDA/STS continuous noise sources and the resulting composite SPL's at 5.0 psia.

The composite SPL's exceed the criteria by less than 3 dB in the 500 and 2000 hertz octave bands and by approximately 6 dB in the 1000 hertz octave band.

3.4.2 Airlock Module (AM) - The sound pressure levels in the AM due to operation of noise sources in the OWS and MDA/STS were estimated using equations 3 and 5 and the appropriate room parameters.

3.4.2.1 AM SPL's Due to MDA/STS Sources - Figure 15 indicates the SPL's in the AM due to operation of the OWS Interconnect Duct Fan, located in the MDA/STS, at 5.0 psia. The SPL's are significantly less than the Skylab Interior Noise Criteria for all octave bands. The SPL's in the AM due to the Condensing Heat Exchanger at 5.0 psia ambient pressure are presented in figure 16. These octave band SPL's also do not exceed the noise criteria.

3.4.2.2 AM SPL's Due to OWS Noise Source - Figures 17 and 18 indicate the SPL's in the AM due to the intermittent operation of the Ergometer at 14.7 and 5.0 psia. At 14.7 psia the SPL's exceed the Skylab Interior Noise Criteria, which is applicable to continuous noise sources, in the 250 through 2000 hertz octave bands. At 5.0 psia the SPL's exceed the criteria in the 250, 500 and 1000 hertz octave bands.

3.4.2.3 AM Composite SPL's Due to Continuous Noise Sources - The SPL's in the AM due to operation of continuous noise sources located in the MDA/STS, AM, and OWS at 5.0 psia are presented in figure 19. The SPL's due to the OWS and MDA/STS noise sources are less than the Skylab Interior Noise Criteria, while the SPL's due to the AM noise source, identified as the OWS Cooling Module, exceed the criteria in the 500, 1000 and 2000 hertz octave bands.

3.4.3 Orbital Workshop (OWS) - The remodeling of the AM and MDA/STS sections does not affect the acoustical properties of the OWS section. Equations (4) and (5) were used with equation (3) to estimate the SPL's in the OWS due to noise sources located in the STS.

3.4.3.1 OWS SPL's Due to MDA/STS Noise Sources - The SPL's due to the OWS interconnect Duct Fan at 5.0 psia are indicated in figure 20, and the SPL's due to operation of the Condensing Heat Exchanger are indicated in figure 21. The SPL's produced by these two noises do not exceed the Skylab Interior Noise Criteria.

3.4.3.2 OWS Composite SPL's Due to Continuous Noise Sources - The estimated octave band sound pressure levels in the OWS at 5.0 psia due to all continuous noise sources are presented in figure 22. All continuous noise sources produce SPL's in the OWS less than the noise criteria, and the resulting composite SPL's are also less than the criteria.

3.5 Skylab Acoustical Environment Map - An update to the preliminary mapping of the Skylab interior acoustic environment during orbital operations is discussed in the following paragraphs. In addition to locating Skylab noise sources, speech interference levels in each Skylab section due to operation of the updated noise source data are presented.

3.5.1 Skylab Equipment and Experiment List - Tabulations of the Skylab equipment and experiments are indicated in Tables III and IV and include several additions to the tabulations described in reference 1. The noise sources identified to date are indicated with an arrow or asterisk in these tables. It should be noted that acoustic data is not yet available for all of the indicated potential noise sources.

3.5.2 Location of Noise Sources - The location of the identified Skylab noise sources are indicated in figures 23 through 28. Figure 23 indicates the Skylab Orbital Configuration, showing the relationships between the MDA, STS, AM and OWS.

Figure 24 depicts the location of the Fan/Muffler Assemblies in the Multiple Docking Adapter. The noise sources located in the AM/STS section are depicted in figures 25 through 26. Orbital Workshop noise sources are indicated in figures 27 and 28. Figure 28 indicates experiment M074, the Specimen Mass Measurements device. The electrical counter in this experiment is considered to be a noise source.

3.5.3 Speech Interference Levels (SIL) - The preferred frequency speech interference level (PSIL) was selected to assess the speech-interfering aspects of the Skylab interior noise sources. The preferred frequency speech interference level is defined as the arithmetic average of the sound pressure levels in each of the three octave bands with center frequencies of 500, 1000, and 2000 hertz. Reference 8 demonstrates that PSIL shows the smallest expected variability over diverse spectra noise compared to other rating methods and recommends the usage of PSIL for assessing the speech-interfering aspects of noise.

The PSIL associated with the Skylab Interior Noise Criteria in figure 1 is 56.7 dB. For this PSIL value, face-to-face communications at 14.7 psia ambient pressure are possible using "a normal voice" when a speaker and listener are less than five feet from each other (see reference 8).

Figures 29 and 30 present the PSIL values in each Skylab section due to operation of the Interconnect Duct Fan, Condensing Heat Exchange and Ergometer. The PSIL's associated with the Ergometer exceed the PSIL of the criteria; however, the Ergometer is an intermittent noise source,and the criteria applies to continuous noise sources.

Another rating system has been suggested which includes the higher frequency noise: The Modified Speech Interference Level (MSIL). MSIL is defined as the arithmetic average of the sound pressure levels in each of the four octave bands with center frequencies of 500, 1000, 2000, and 4000 hertz. No correlation between MSIL and speech interfering effects have been reported; however, the MSIL permits a comparison of the noise produced by equipment of a broad frequency range. The frequency range of the MSIL is similar to the frequency range of the SIL (reference 7). The range of the MSIL is 354 to 5660 hertz, while the frequency range of the SIL is 600 to 4800 hertz. The MSIL associated with the Skylab Interior Noise Criteria is 56.25. Figures 29 and 30 present the MSIL values in each Skylab section due to operation of the Ergometer, Interconnect Duct Fan and Condensing Heat Exchanger.

3.6 Additional Acoustic Data - Acoustic data which may be of an experimental nature are discussed in this report. In addition to these data, updated or new acoustic data applicable to several other Skylab noise sources should be received in the near future and will be presented at that time. A description of some of these applicable noise sources is listed in the following paragraphs:

a. STS Teleprinter. MDAC-E has recently modified the Teleprinter by enclosing portions of it with sponge rubber and 0.032 inch thick lead, in an attempt to obtain additional noise reduction.

b. Cabin Heat Exchanger Fan/Muffler (CHEM). The three fan mode of operation exhibits the highest SPL's and will be the mode of operation used in additional AM/STS analyses in this report. This mode of operation exceeds the Skylab Interior Noise Criteria at several octave band frequencies for both the 14.7 and 5.0 psia ambient pressure conditions. Additional acoustic tests are planned by MDAC-E utilizing different bellmouth shapes, in an attempt to obtain additional noise reduction for the noise source.

c. OWS Cooling Module Fan/Muffler. The four fan mode of operation exhibits the highest SPL's. It should be noted that the 5.0 psia ambient pressure SPL's are more severe than the SPL's at 14.7 psia ambient pressure. This is due to extrapolated PWL data supplied by MDAC-E based on similar fan data which was measured at 5.0 psia ambient pressure.

   Additional tests are planned by MDAC-E using several other bellmouth shapes in an attempt to obtain additional noise reduction.

d. During System Assurance Tests (SAT) of the AM/STS/MDA in the MDAC-E vacuum chamber acoustic data should be obtained applicable to AM/STS and MDA fan noise sources and can be used for update and verification purposes.

e. During subsystem tests in the OWS at MDAC-W acoustic measurements shall be obtained, and these data will be reviewed and correlated with existing data.

4. CONCLUSIONS

4.1 Airlock Module/Structural Transition Section

a. The OWS Interconnect Duct Fan has been modified to decrease the peak octave band sound pressure level. The resulting SPL's do not exceed the Skylab Interior Noise Criteria.

b. Condensing Heat Exchanger SPL's in the AM/STS exceed the SPL criteria at 5.0 psia in the mid-frequency range. MDAC-E has recently made several modifications to this noise source and the SPL's reported herein reflect these modifications, resulting in a significant reduction in the high frequency noise.

4.2 Orbital Workshop Section

a. The M171 Ergometer is considered to be an intermittent noise source. Utilizing PWL data based on OWS Mockup tests, the resulting SPL's exceed the Skylab Interior Noise Criteria for continuous noise sources by 10 to 20 dB, for both 14.7 and 5.0 psia ambient pressures. Both direct and reverberant sound energy effects were incorporated into the analysis.

b. The M074 Specimen Mass Measurements and the M172 Body Mass Measurements have been identified as intermittent noise sources. Measurements of noise emitted from a flight article with a sound level meter indicate a reading of 88dBA near the source and 80dBA near the operator's ear. However, this high frequency noise source is not expected to be hazardous.

c. The M131 Revolving Chair has been identified as an intermittent noise source. No data are available to date.

4.3 Composite Sound Pressure Levels - Based on composite SPL figures in this report, the following comments are presented:

4.3.1 Airlock Module -

a. Composite SPL's in the AM at 5.0 psia due to operation of OWS continuous noise sources do not exceed the acoustic criteria and are not considered as a significant noise contribution factor in the AM.

b. Composite SPL's in the AM at 5.0 psia ambient pressure due to MDA/STS continuous noise sources do not exceed the acoustic criteria.

c. Composite SPL's in the AM due to all continuous noise sources at 5.0 psia exceed the criteria by as much as 10dB in the 250 through 2000 hertz octave bands. The major contributor to this exceedence is the OWS Cooling Module located in the AM.

4.3.2 MDA/STS -

a. The continuous noise sources in the OWS produce composite SPL's in the MDA/STS that do not exceed the acoustic criteria.

b. The OWS Cooling Module, located in the AM, produces SPL's in the MDA/STS which exceed the acoustic criteria for the 1000 hertz octave band at 5.0 psia.

c. The composite SPL's due to MDA/STS continuous sources exceed the acoustic criteria at 5.0 psia by less than 3 dB in the 1000 hertz octave band.

4.3.3 Orbital Workshop -

a. The composite SPL's in the OWS due to operation of the AM, STS, and MDA continuous noise sources do not exceed the acoustic criteria.

b. Operation of all OWS continuous noise sources (and including the three portable fans) produce composite SPL's which do not exceed the acoustic criteria at 5.0 psia ambient pressure.

4.4 General Items

a. Acoustic data are not available for all of the indicated potential noise sources. As these data become available they should be analyzed since they may be significant noise sources.

b. No acoustic criteria is presently defined applicable to intermittent noise sources.

5. RECOMMENDATIONS

a. Reverberation time data used to estimate MDA/STS/AM SPL's discussed in this report are of a preliminary nature. Due to the approximations involved, reverberation time data should be obtained during MDA/STS/AM vacuum chamber tests scheduled to be performed at MDAC-E, in order to verify and update the analyses contained herein.

b. Acoustic data relating to recent modifications incorporated by MDAC-E applicable to the Teleprinter should be obtained and used to verify or update the analyses contained herein.

c. Acoustic data applicable to OWS noise sources and informally received from MDAC-W should be verified and updated as measured acoustic data are made available.

d. An acoustic criteria applicable to intermittent noise sources should be investigated.

e. The effects of reduced pressure on speech and hearing should be investigated, in addition to sounds in the Skylab orbital environment which may produce fatigue or annoyance as a result of long term exposure.

f. Interior noise level measurements should be obtained during the Skylab mission. These data should be analyzed and correlated with the predicted levels.

g. Additional acoustic data should be obtained applicable to the IMC fans in order to ascertain their effect on Skylab SPL's as compared to the PLV fans.

h. Acoustic data to be obtained during system and subsystem tests at MDAC-E and MDAC-W applicable to the AM/STS/MDA and the OWS should be reviewed and correlated.

6. NOTES

6.1 Abbreviations - The following abbreviations are used in this report:

$\bar{\alpha}$	- Average Absorption Coefficient
AM	- Airlock Module
CHEM	- Cabin Heat Exchanger Module
dB	- Decibels
dBA	- Decibels measured with A-weighting network
DTA	- Dynamic Test Article
°F	- Temperature, Farenheit
ft	- Feet
Hz	- Hertz (cycles per second)
IMC	- IMC Magnetics Corporation
$\log_{10}$	- Logarithm to the base 10
MDA	- Multiple Docking Adapter
MDAC-E	- McDonnell Douglas Astronautics Company - Eastern Division
MDAC-W	- McDonnell Douglas Astronautics Company - Western Division
Microbar	- A pressure of One Dyne Per Square Centimeter
MMC	- Martin Marietta Corporation
MSC	- Manned Spacecraft Center
MSFC	- Marshall Space Flight Center

MSIL	- Modified Speech Interference Level
NASA	- National Aeronautics and Space Administration
O.B.	- Octave Band
OWS	- Orbital Workshop
P	- Pressure
PLV	- Post Landing Ventilation
psi	- Pounds Per Square Inch
psia	- Pounds Per Square Inch, Absolute
PSIL	- Preferred Speech Interference Level
PWL	- Acoustic Power Level
R	- Room Constant
Ref	- Reference
S	- Area
SIL	- Speech Interference Level
SPL	- Sound Pressure Level, dB
STS	- Structural Transition Section
SWS	- Saturn Workshop
T_{60}	- Reverberation Time, Seconds
TL	- Transmission Loss, dB
V	- Volume
VCS	- Ventilation Control System

6.2 References - The following documents are referenced in the text by number only:

1. Baratono, John R., Hellweg, R. D., and Rader, W.P., Skylab Interior Acoustic Environment Report, Technical Report ED-2002-1200-5, Martin Marietta Corporation, Denver, Colorado: 30 November 1971.

2. Rader, W.Paul, Preliminary Saturn Workshop (SWS) Acoustical Environmental Mapping, Technical Report ED-2002-1055, Martin Marietta Corporation, Denver, Colorado: July 1, 1970.

3. MSFC, Configuration Control Board Directive, CCBD No. 314-71-0050, May 20, 1971.

4. Baratono, John R., and Rader, W. Paul, Skylab Interior Acoustic Environment Report, Technical Report ED-2002-1200-1, Martin Marietta Corporation, Denver, Colorado: October 30, 1970.

5. Baratono, John R., and Rader, W. Paul, Skylab Interior Acoustic Environment Report, Technical Report ED-2002-1200-3, Martin Marietta Corporation, Denver, Colorado: April 30, 1971.

6. Baratono, John R., and Rader, W. Paul, Skylab Interior Acoustic Environment Report, Technical Report, ED-2002-1200-4, Martin Marietta Corporation, Denver, Colorado: July 31, 1971.

7. Beranek, Leo L, Acoustics, McGraw-Hill Book Company, Inc, New York, 1954.

8. Webster, John C. "SIL-Past, Present, and Future." Sound and Vibration, 3 (August, 1969), 22 thru 26.

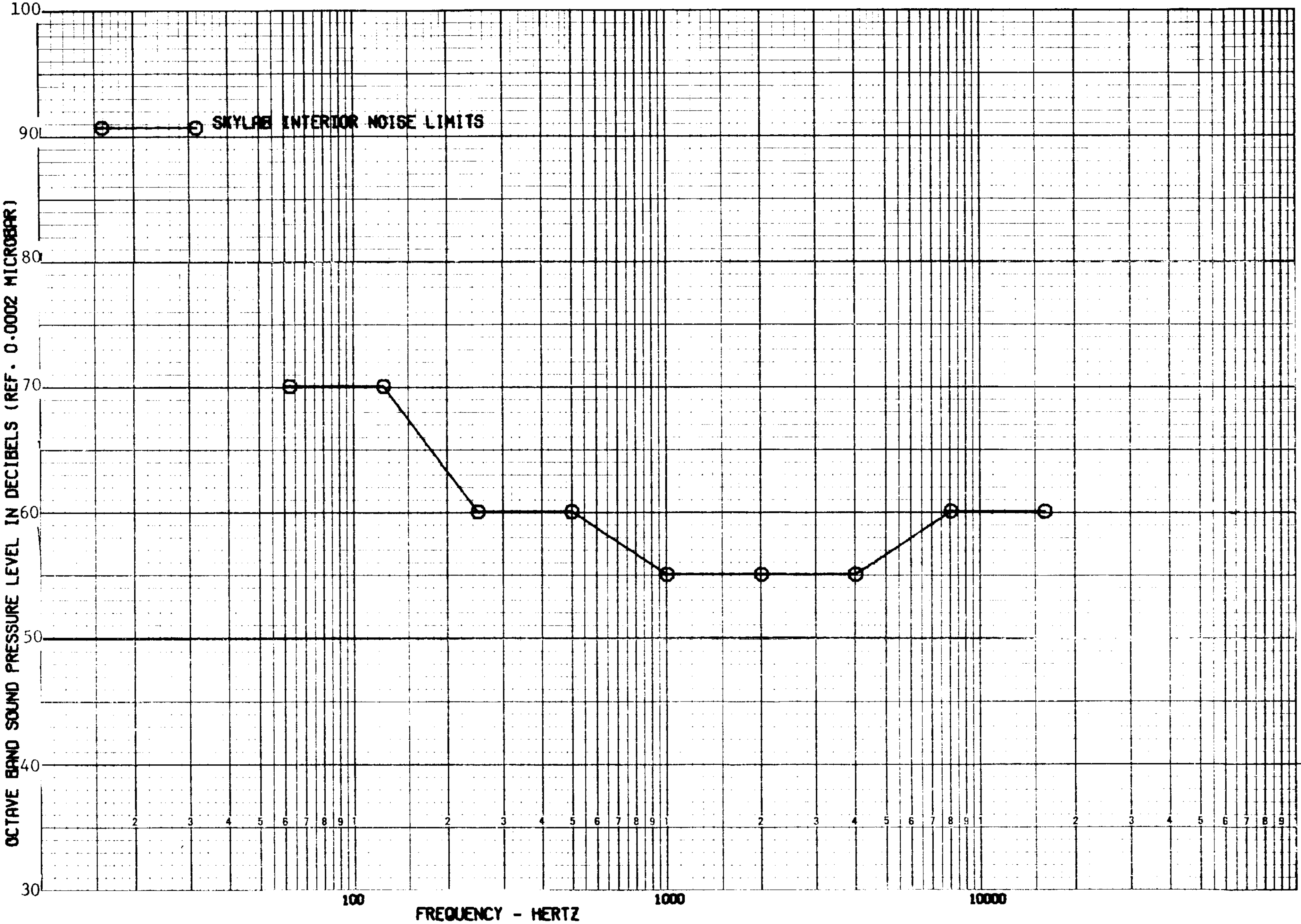

FIGURE 1. ACOUSTICAL NOISE LIMITS ACCEPTABLE FOR CONTINUOUS EXPOSURE

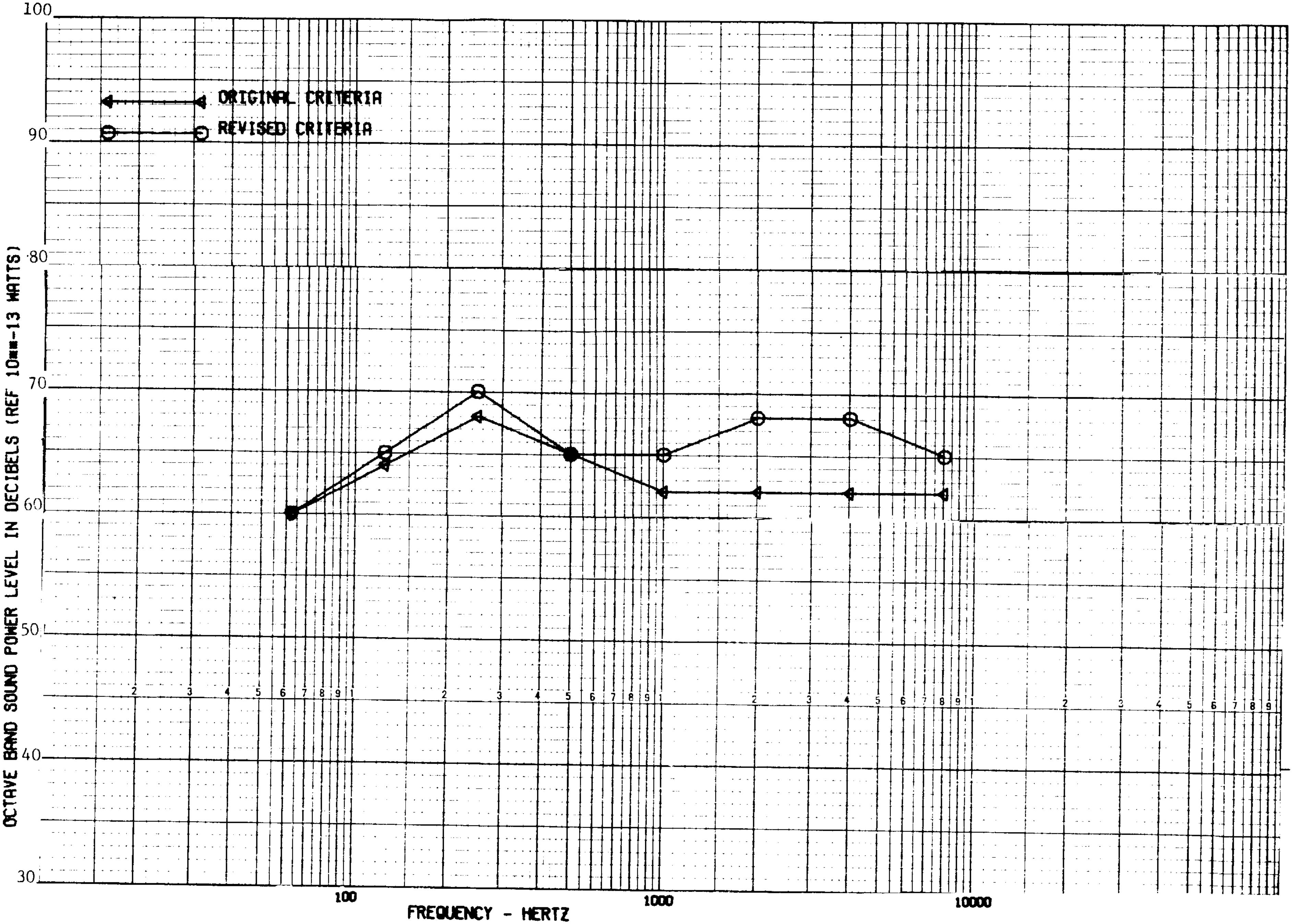

FIGURE 2. COMPARISON OF MDA FAN/MUFFLER PWL ACOUSTIC CRITERIA

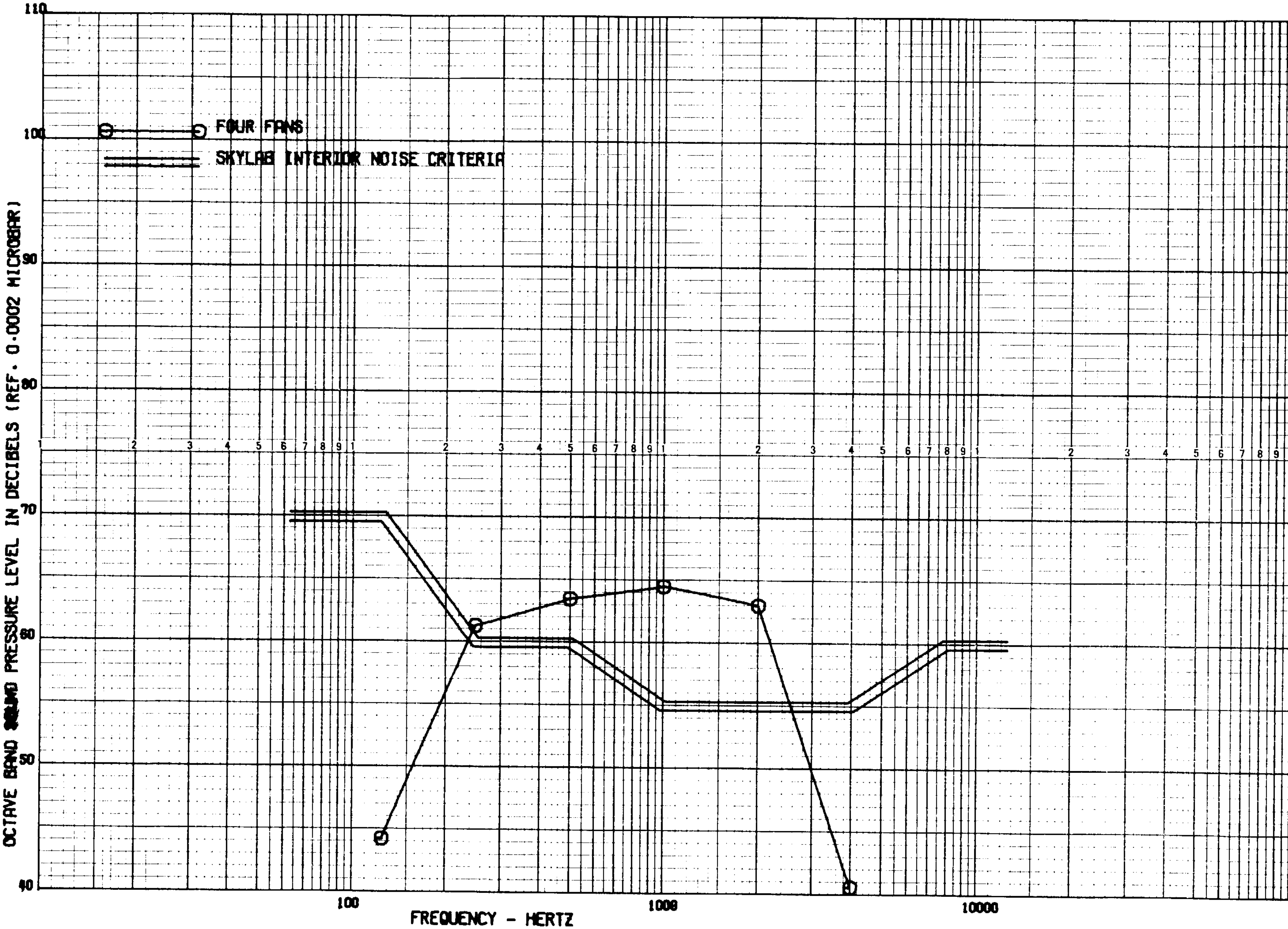

FIGURE 3. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM/STS DUE TO OWS COOLING MODULE AT 5.0 PSIA

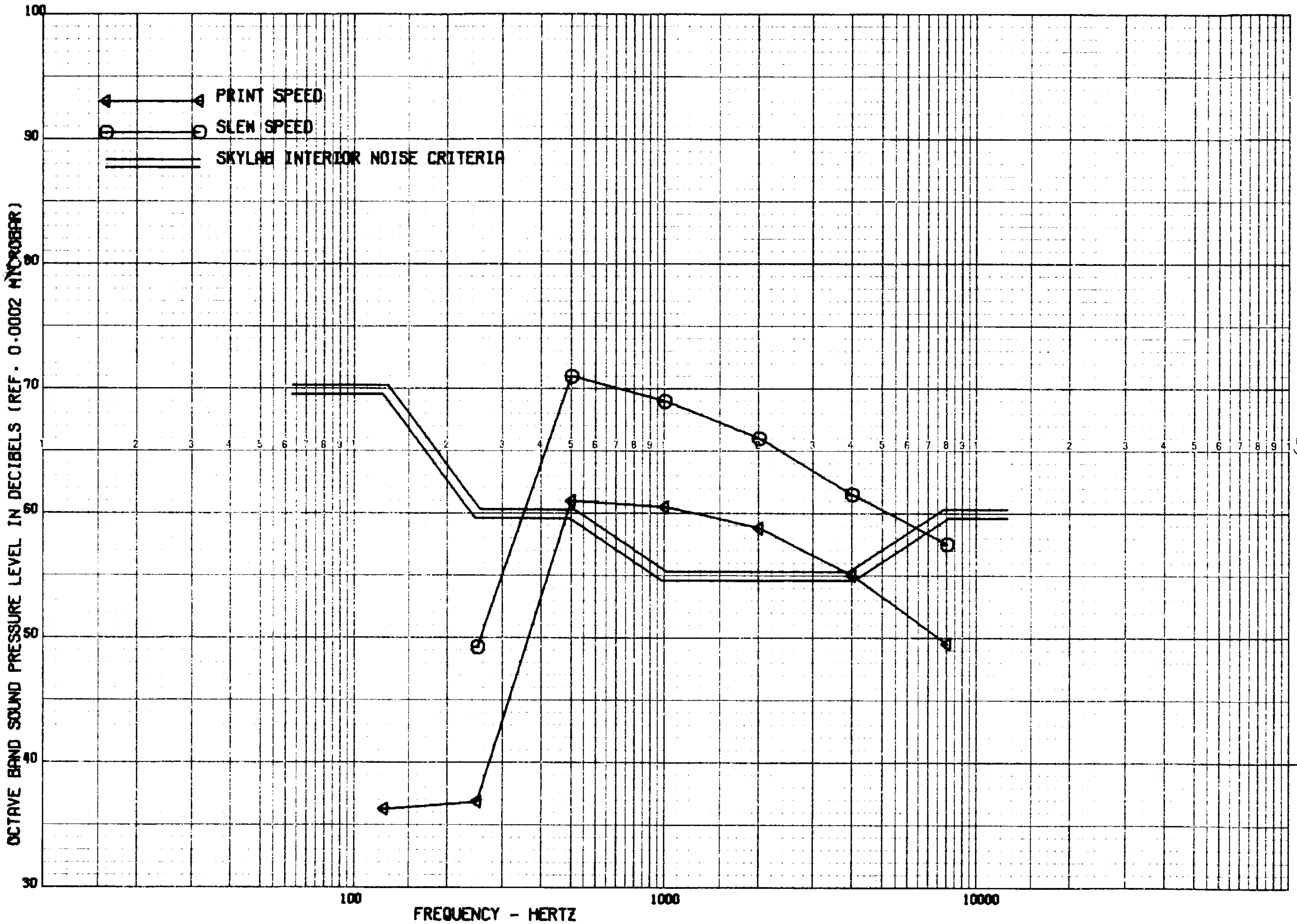

FIGURE 4. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM/STS DUE TO TELEPRINTER AT 5.0 PSIA

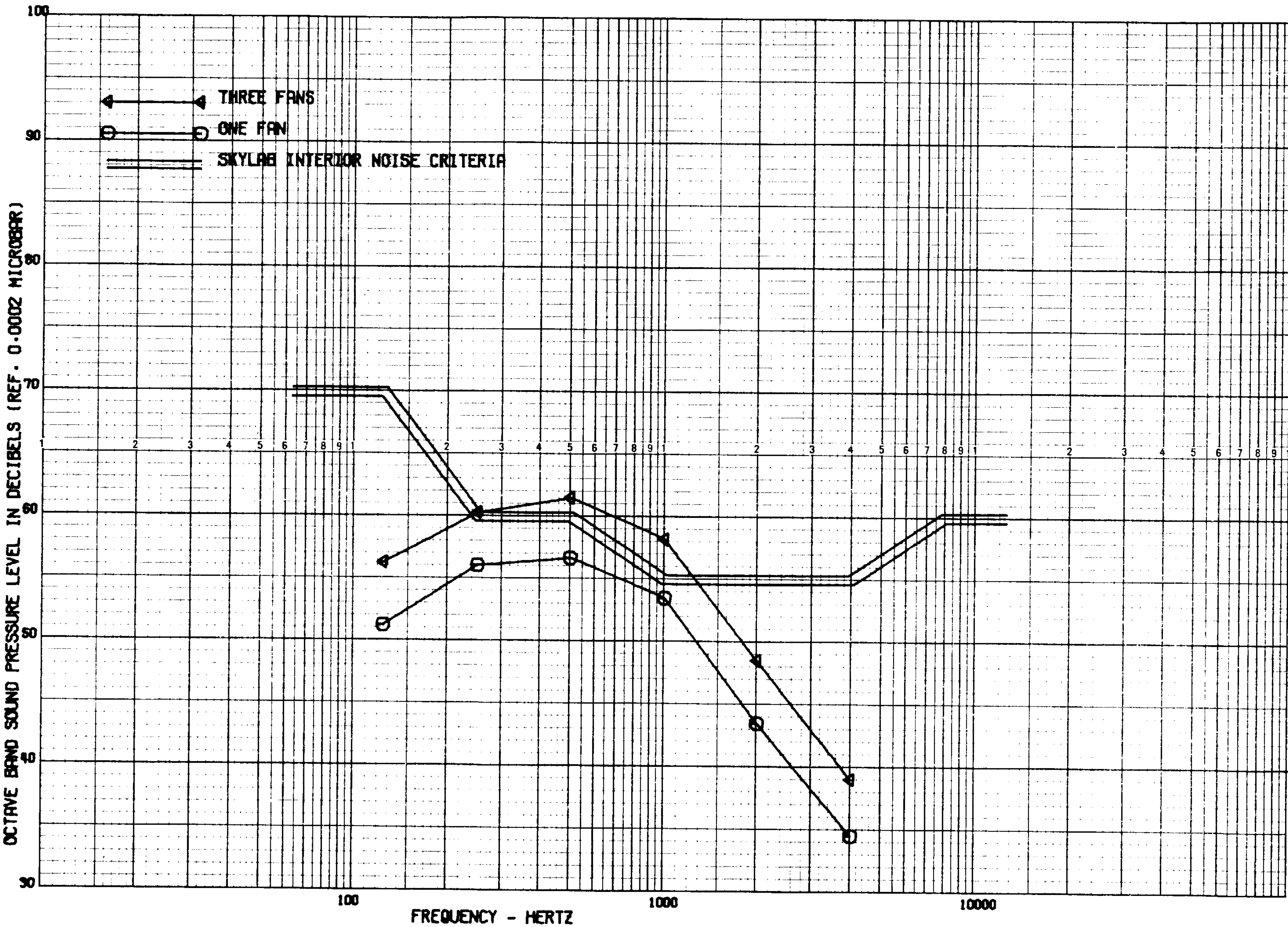

FIGURE 5. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM/STS DUE TO CABIN HEAT EXCHANGER FAN/MUFFLER AT 5.0 PSIA

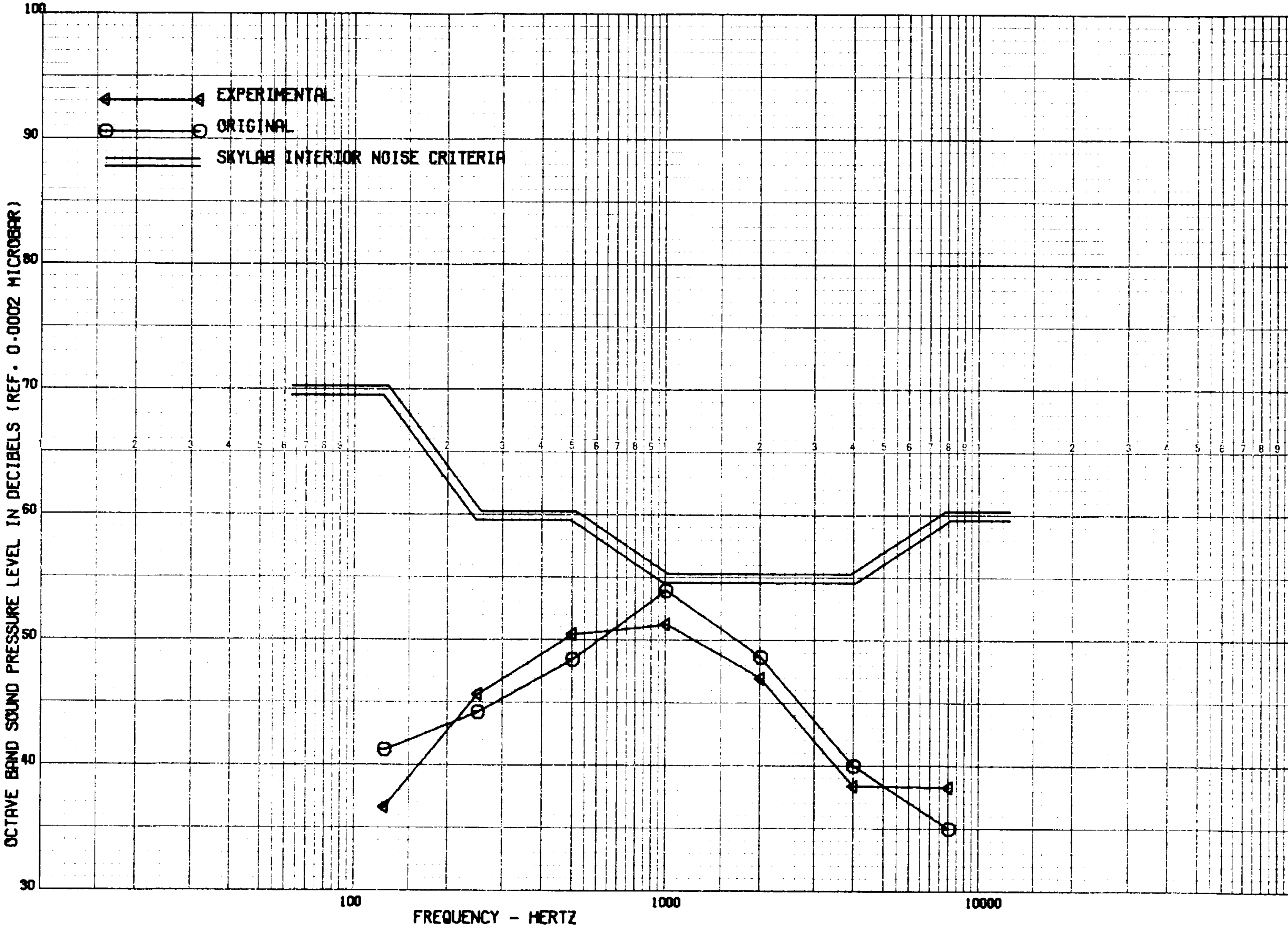

FIGURE 6. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM/STS DUE TO OWS INTERCONNECT DUCT FAN/MUFFLER AT 5.0 PSIA

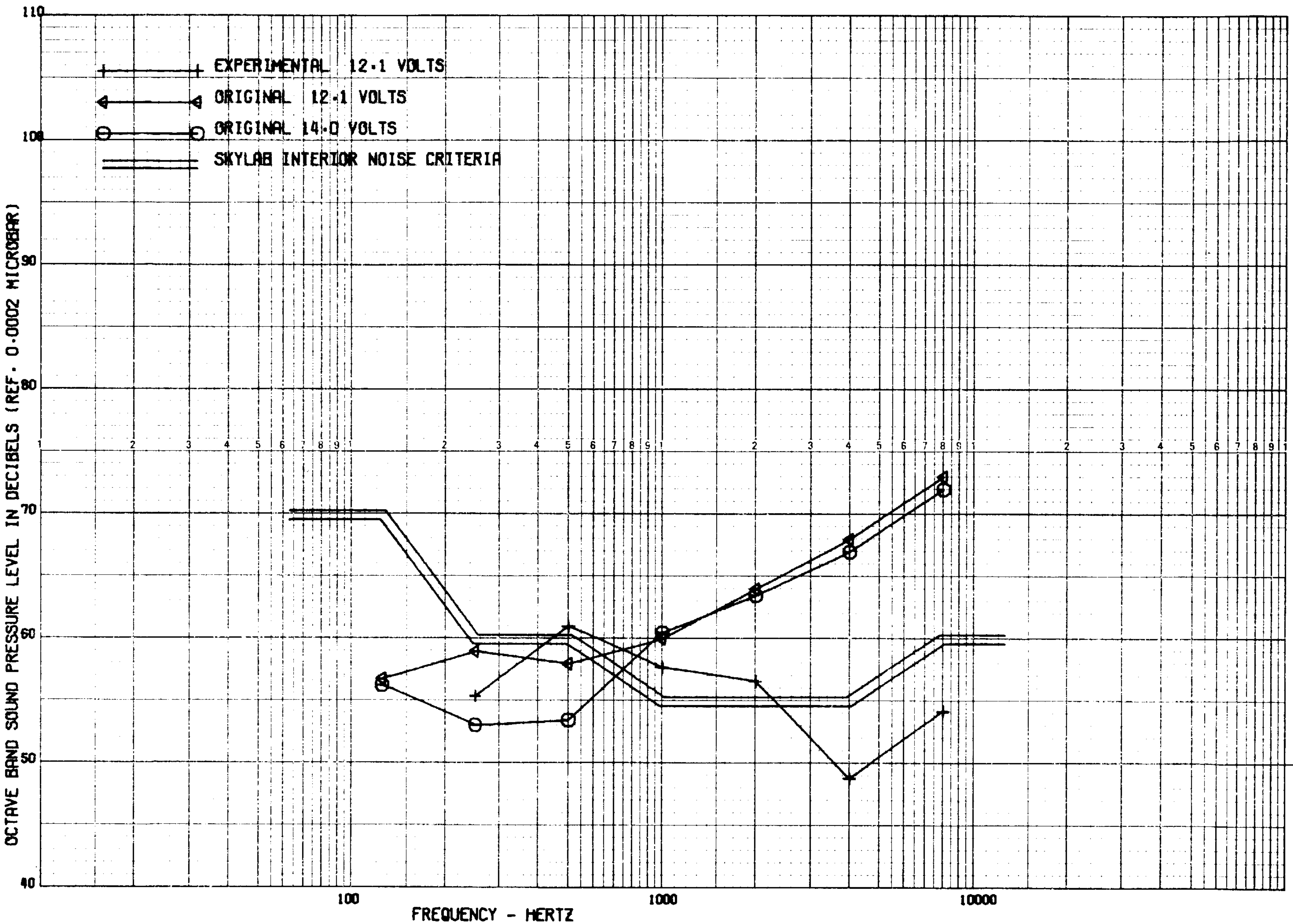

FIGURE 7 . ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM/STS DUE TO CONDENSING HEAT EXCHANGER AT 5·0 PSIA

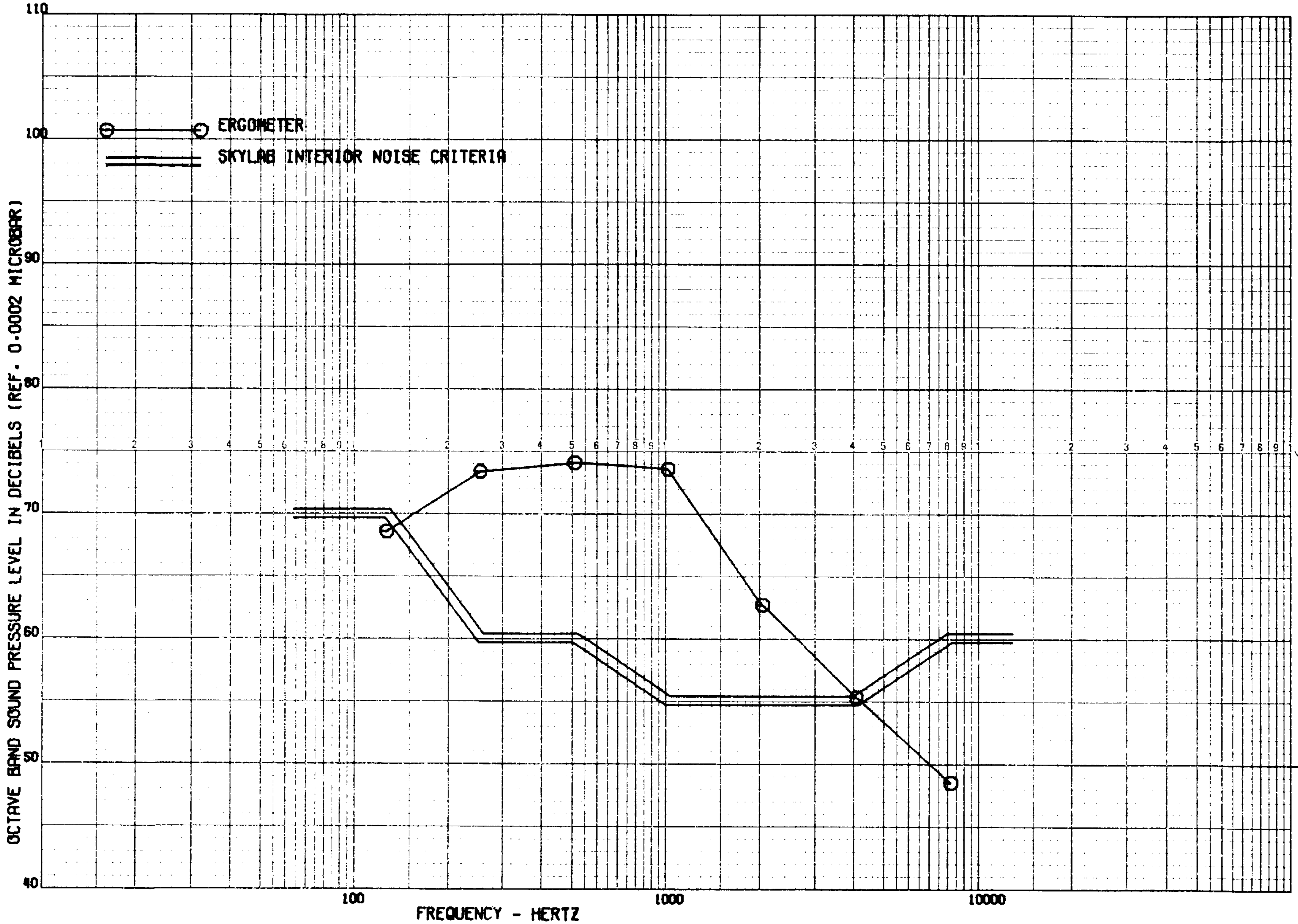

FIGURE 8. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN OWS DUE TO ERGOMETER AT 14.7 PSIA

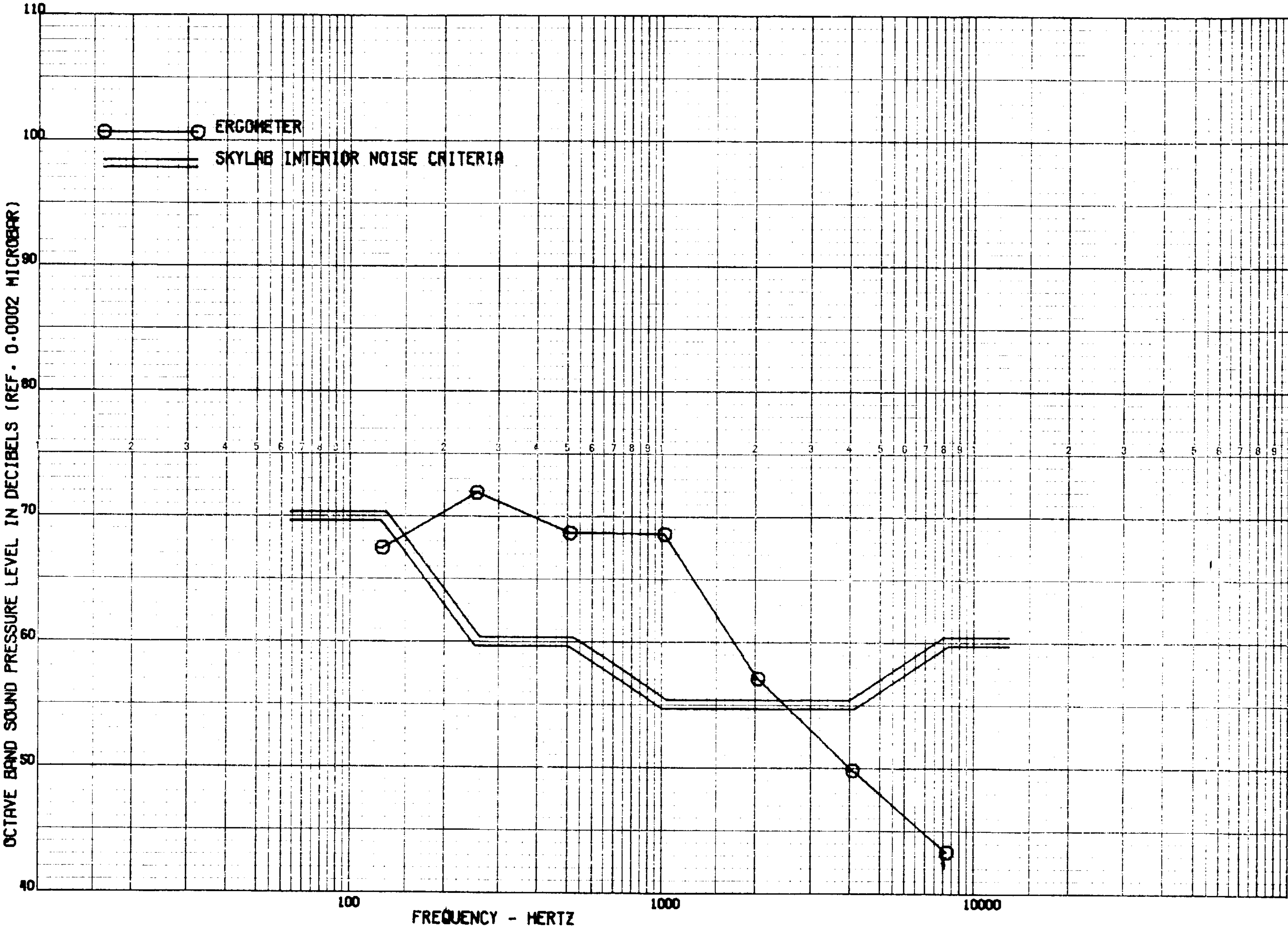

FIGURE 9. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN OWS DUE TO ERGOMETER AT 5.0 PSIA

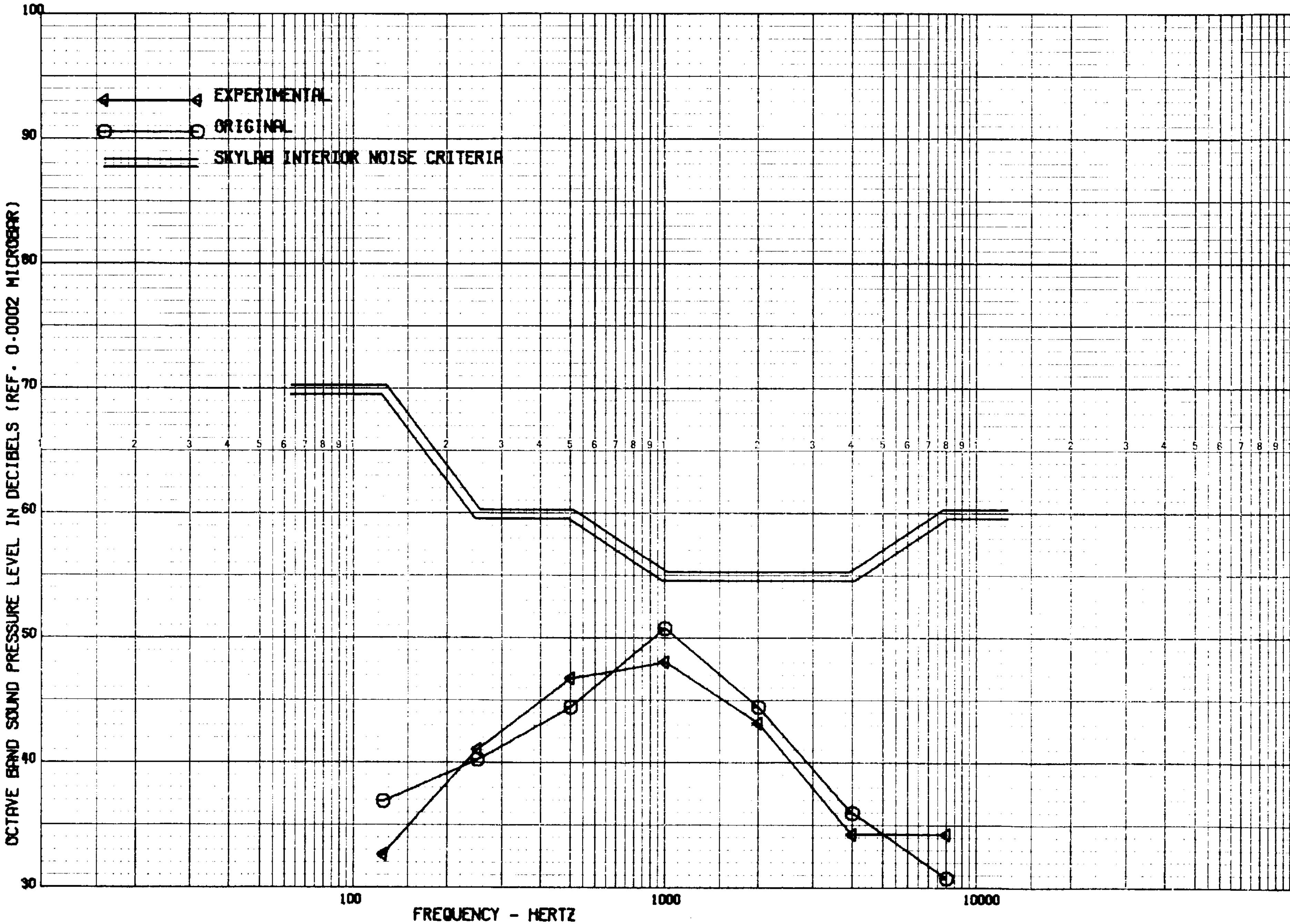

FIGURE 10. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN MDA/STS DUE TO OWS INTERCONNECT DUCT FAN/MUFFLER AT 5.0 PSIA

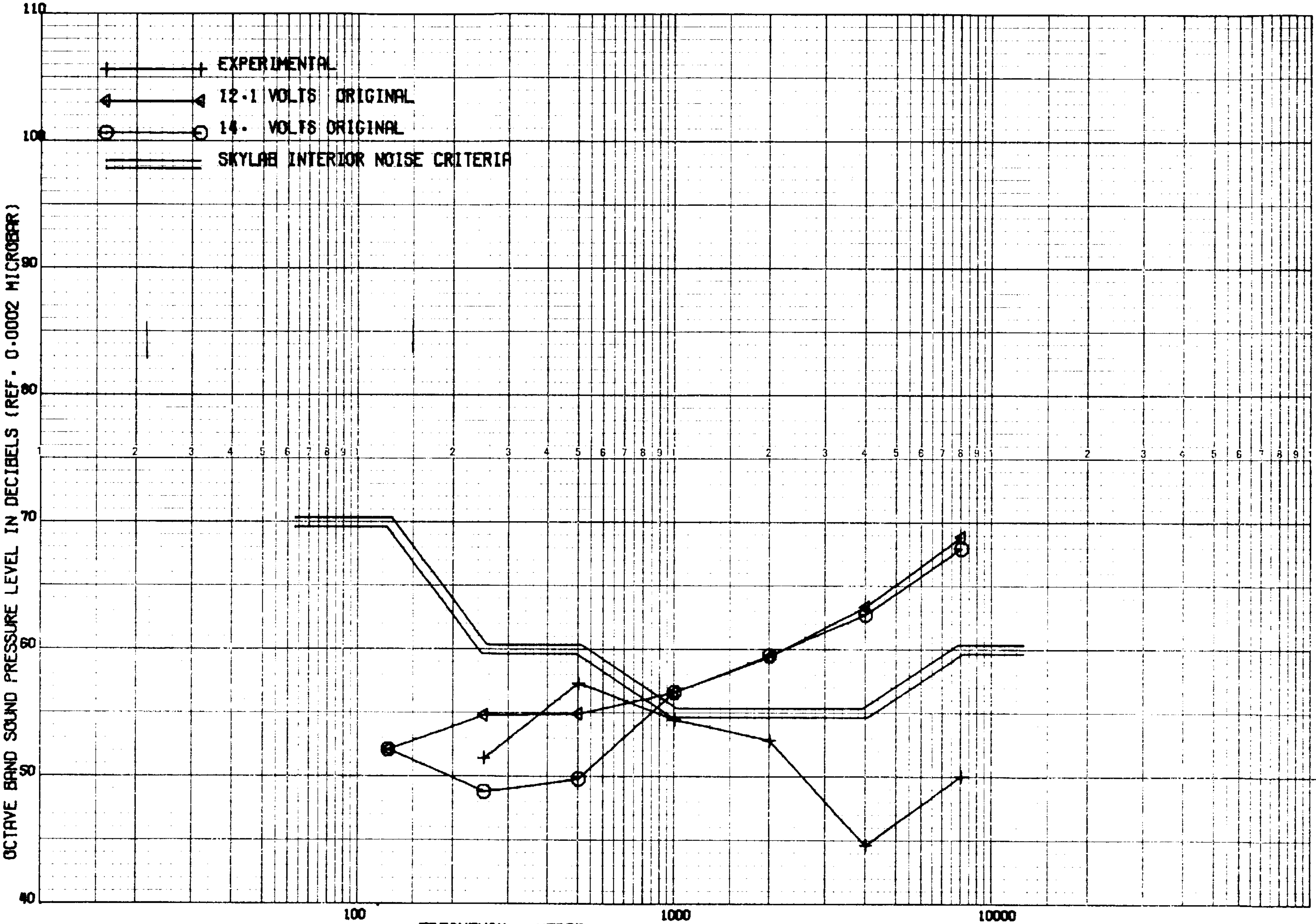

FIGURE 11. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN MDA/STS DUE TO CONDENSING HEAT EXCHANGER AT 5.0 PSIA

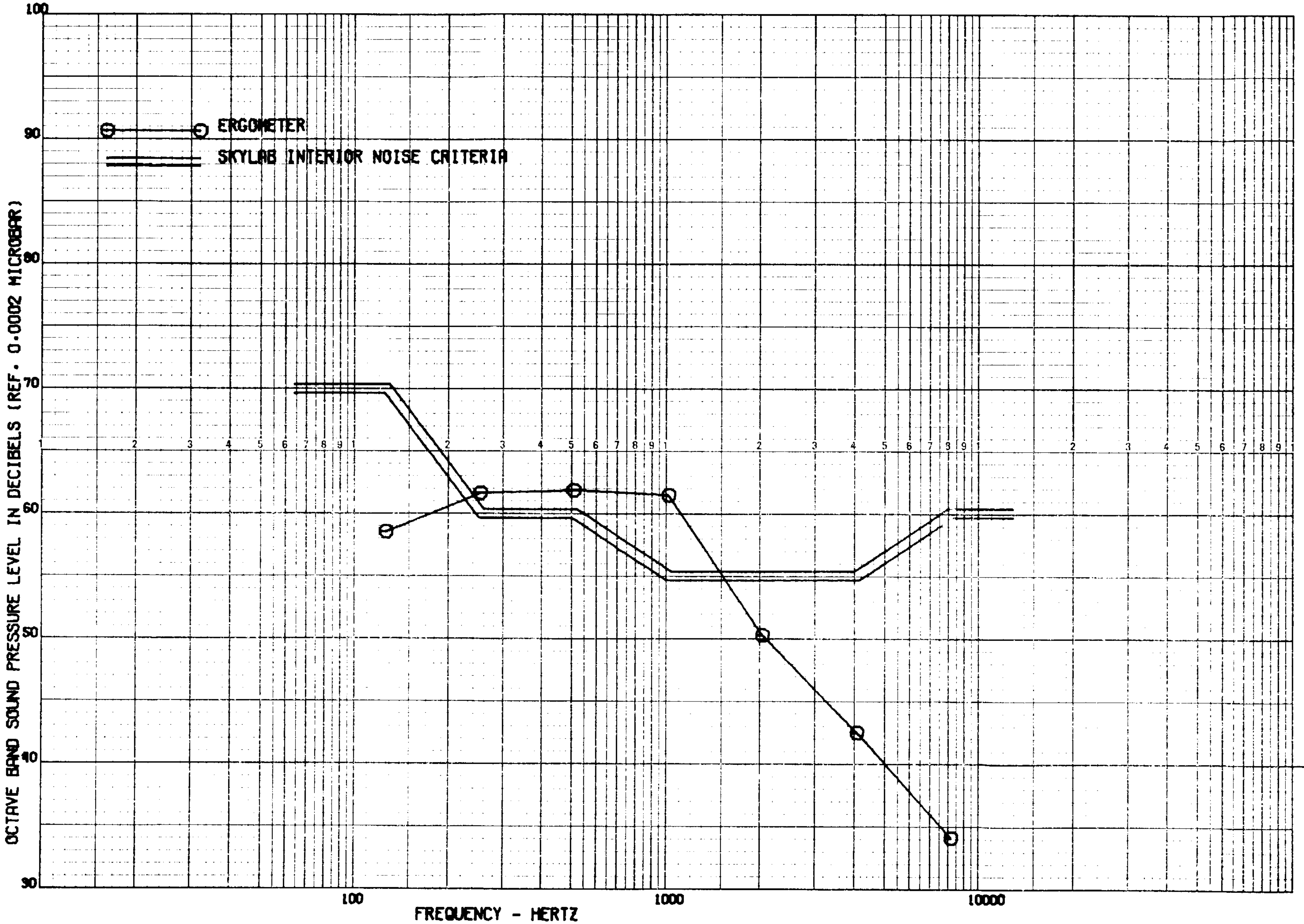

FIGURE 12. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN MDA/STS DUE TO ERGOMETER AT 14.7 PSIA

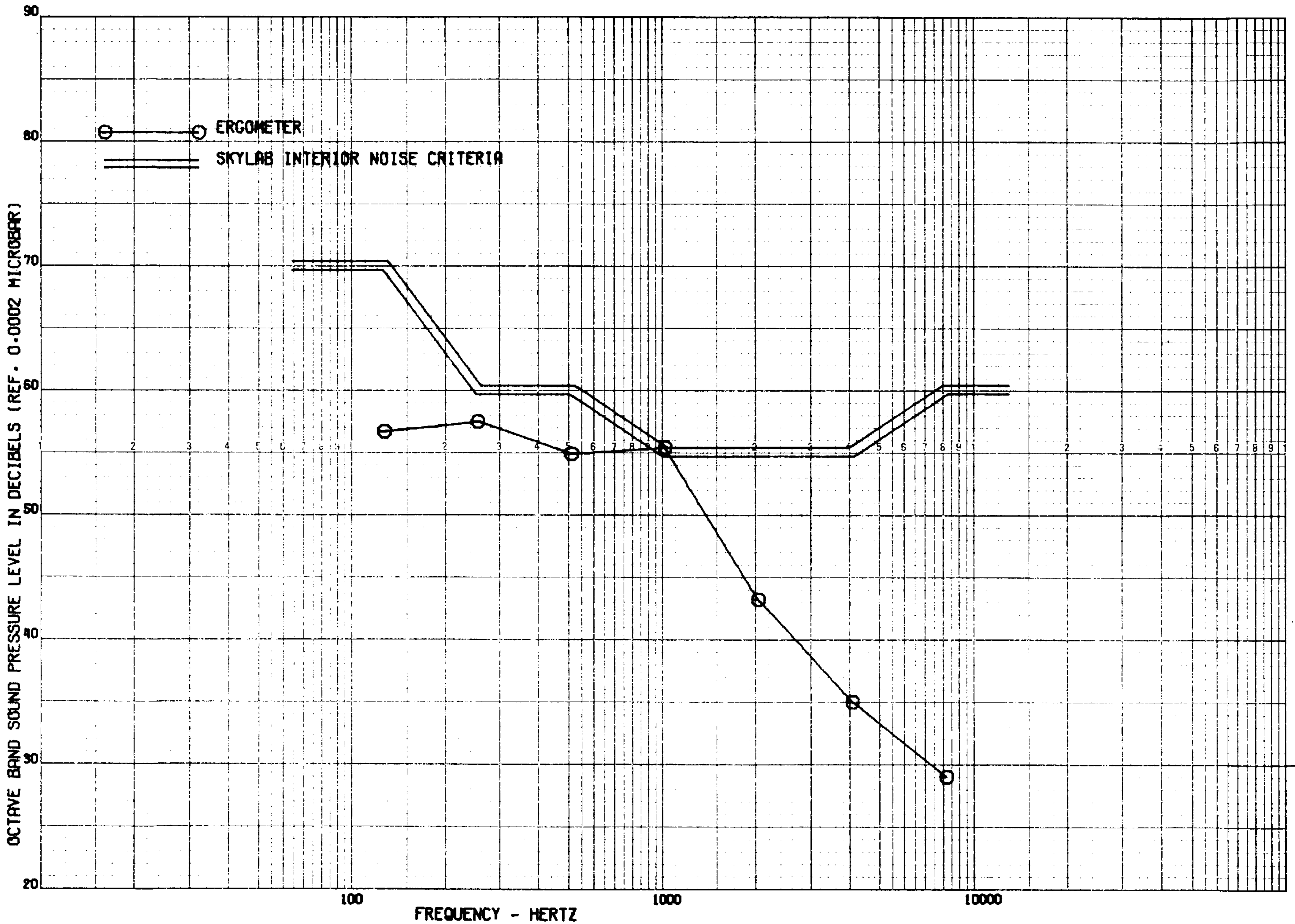

FIGURE 13. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN MDA/STS DUE TO ERGOMETER AT 5.0 PSIA

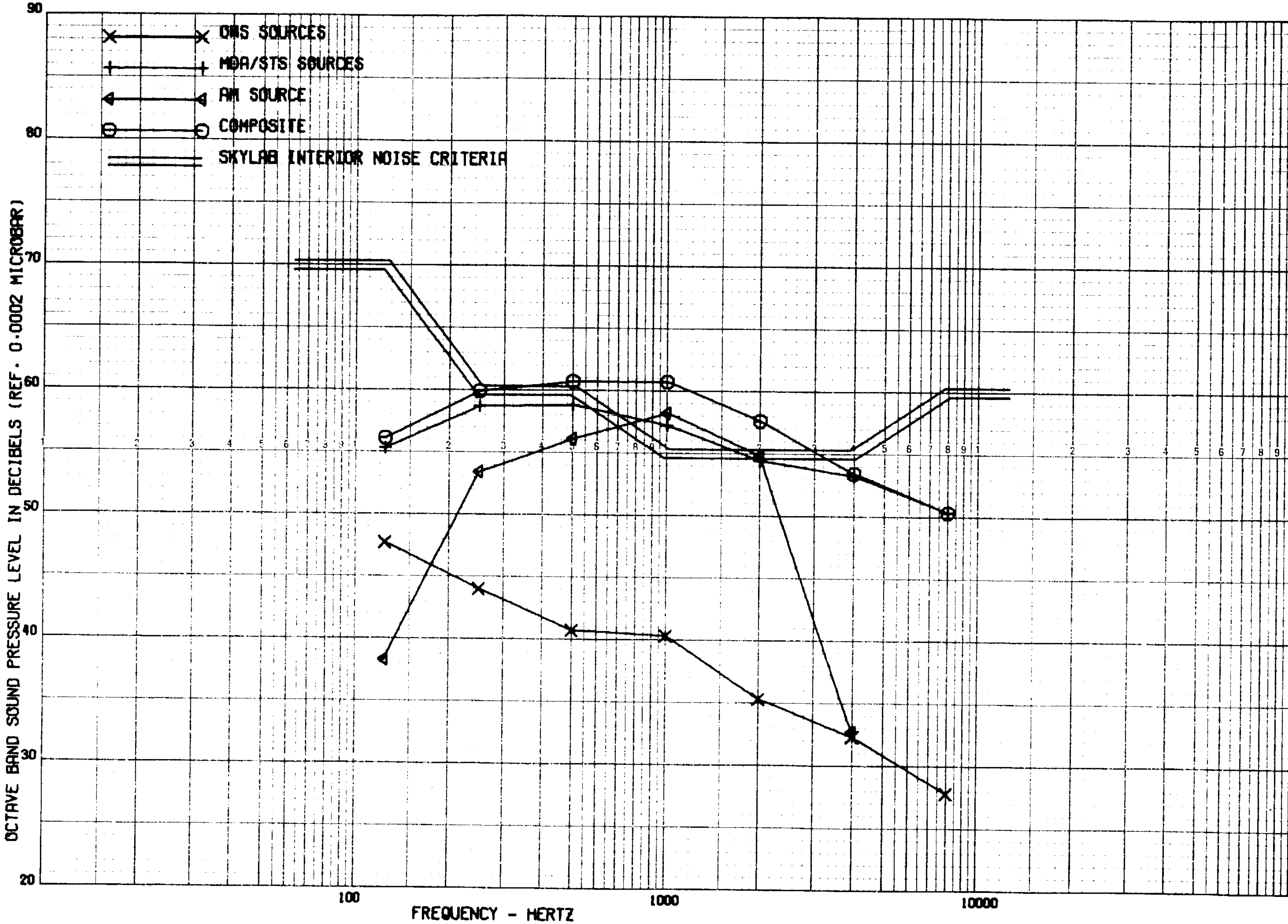

FIGURE 14. ESTIMATED COMPOSITE OCTAVE BAND SOUND PRESSURE LEVEL IN MDA/STS DUE TO CONTINUOUS NOISE SOURCES AT 5.0 PSIA

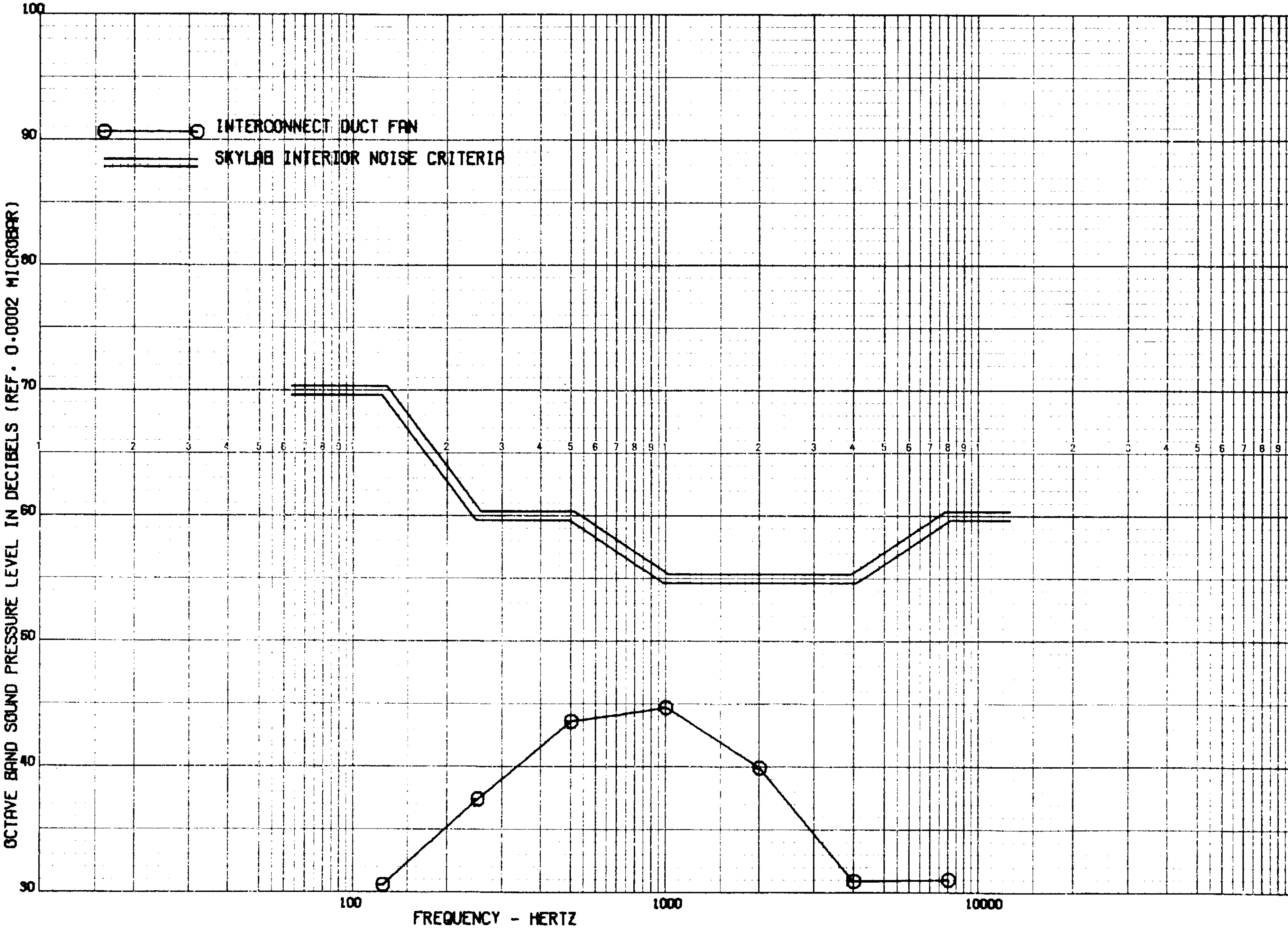

FIGURE 15. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM DUE TO OWS INTERCONNECT DUCT FAN AT 5.0 PSIA

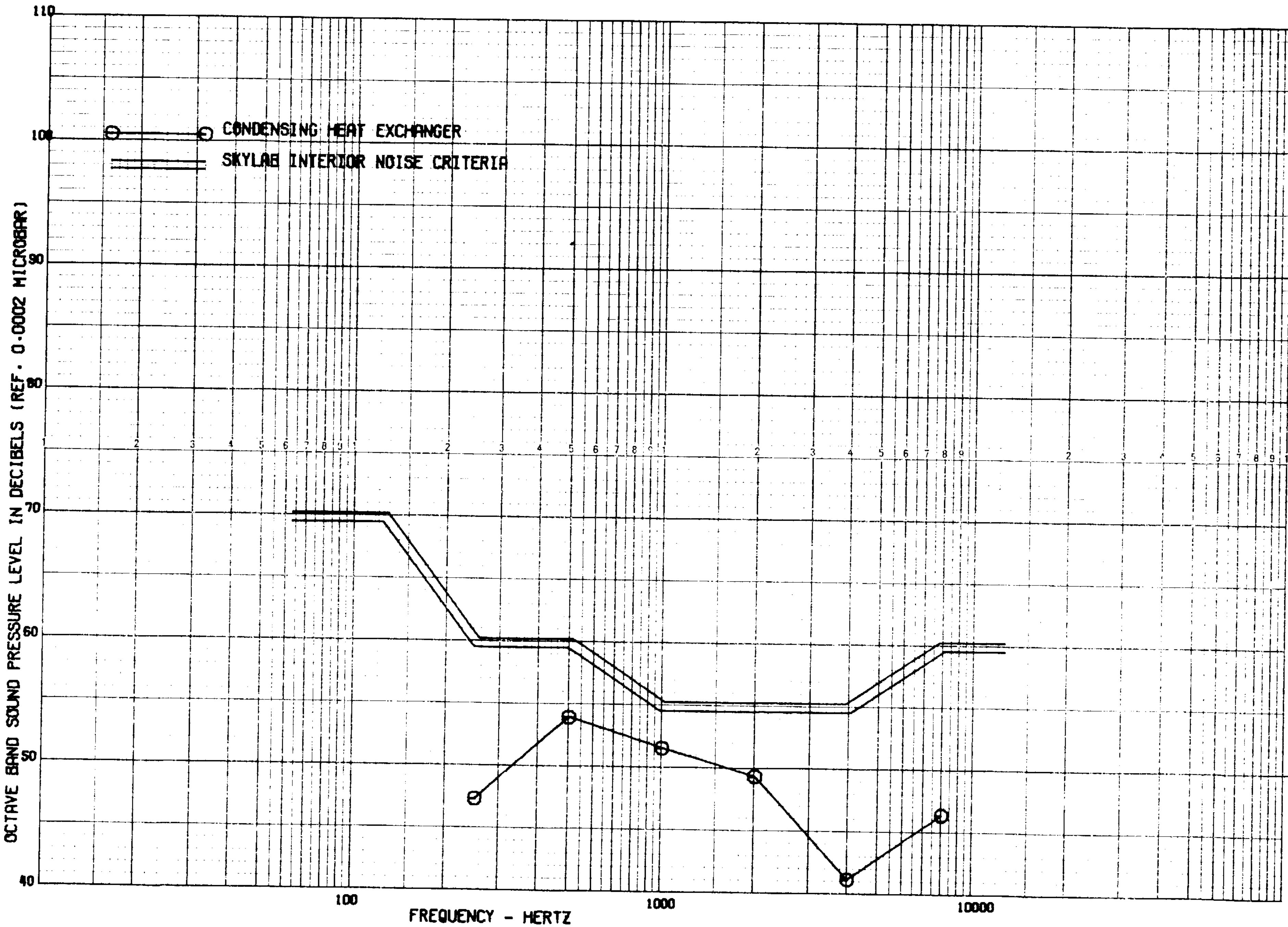

FIGURE 16. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM DUE TO CONDENSING HEAT EXCHANGER AT 5.0 PSIA

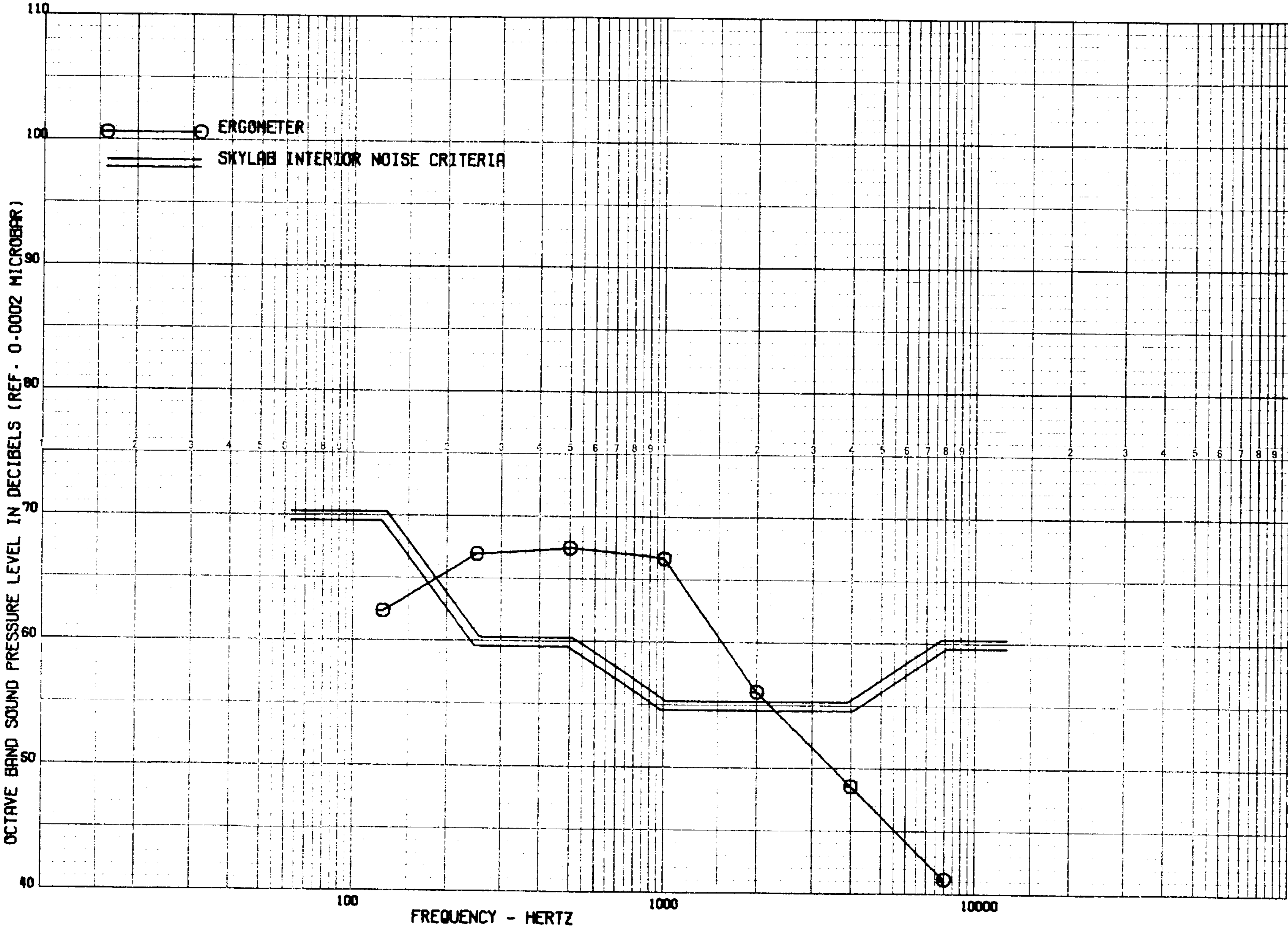

FIGURE 17. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM DUE TO ERGOMETER AT 14.7 PSIA.

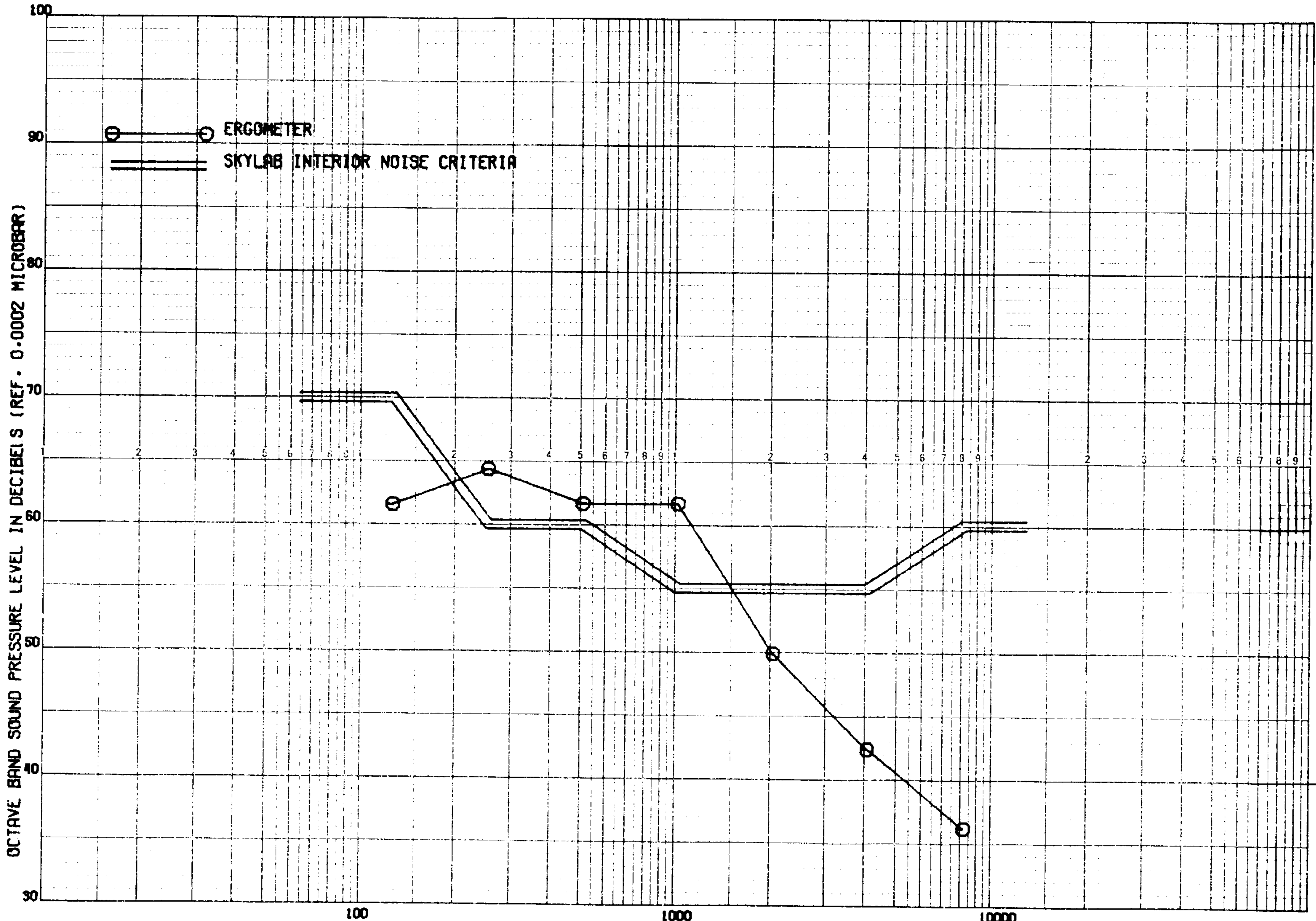

FIGURE 18. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN AM DUE TO ERGOMETER AT 5.0 PSIA

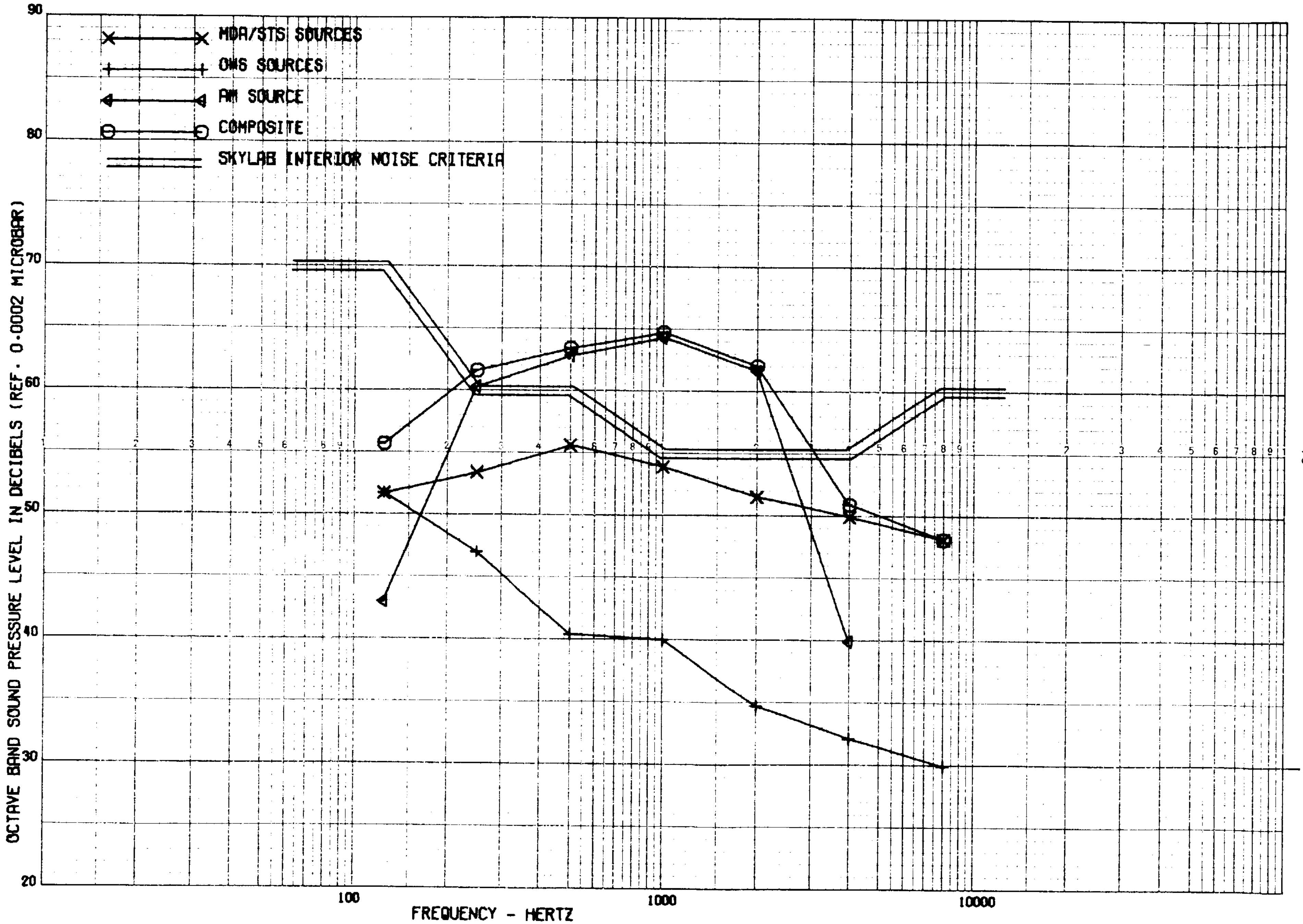

FIGURE 19. ESTIMATED COMPOSITE OCTAVE BAND SOUND PRESSURE LEVEL IN AM DUE TO CONTINUOUS NOISE SOURCES AT 5.0 PSIA

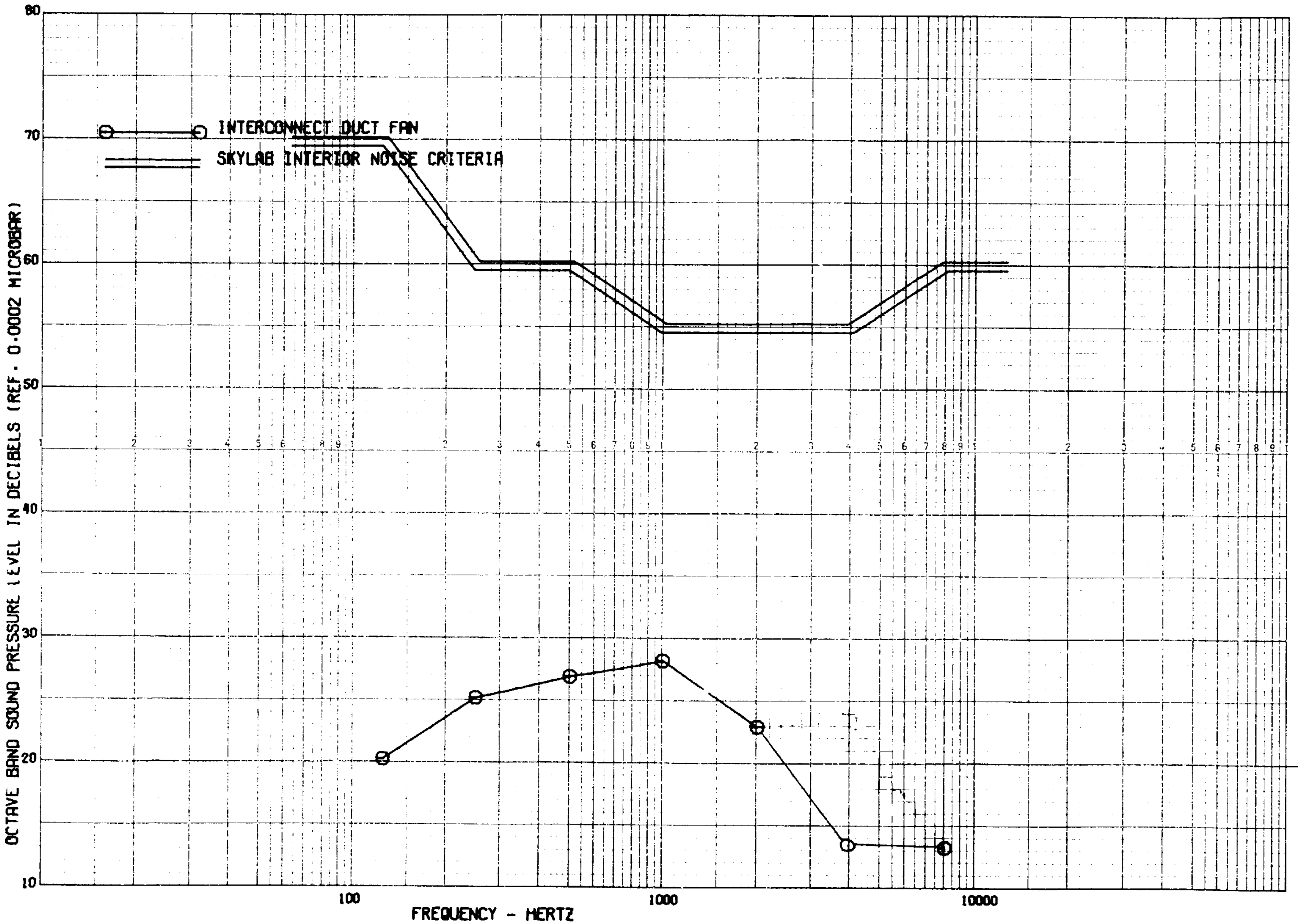

FIGURE 20. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN OWS DUE TO OWS INTERCONNECT DUCT FAN AT 5.0 PSIA

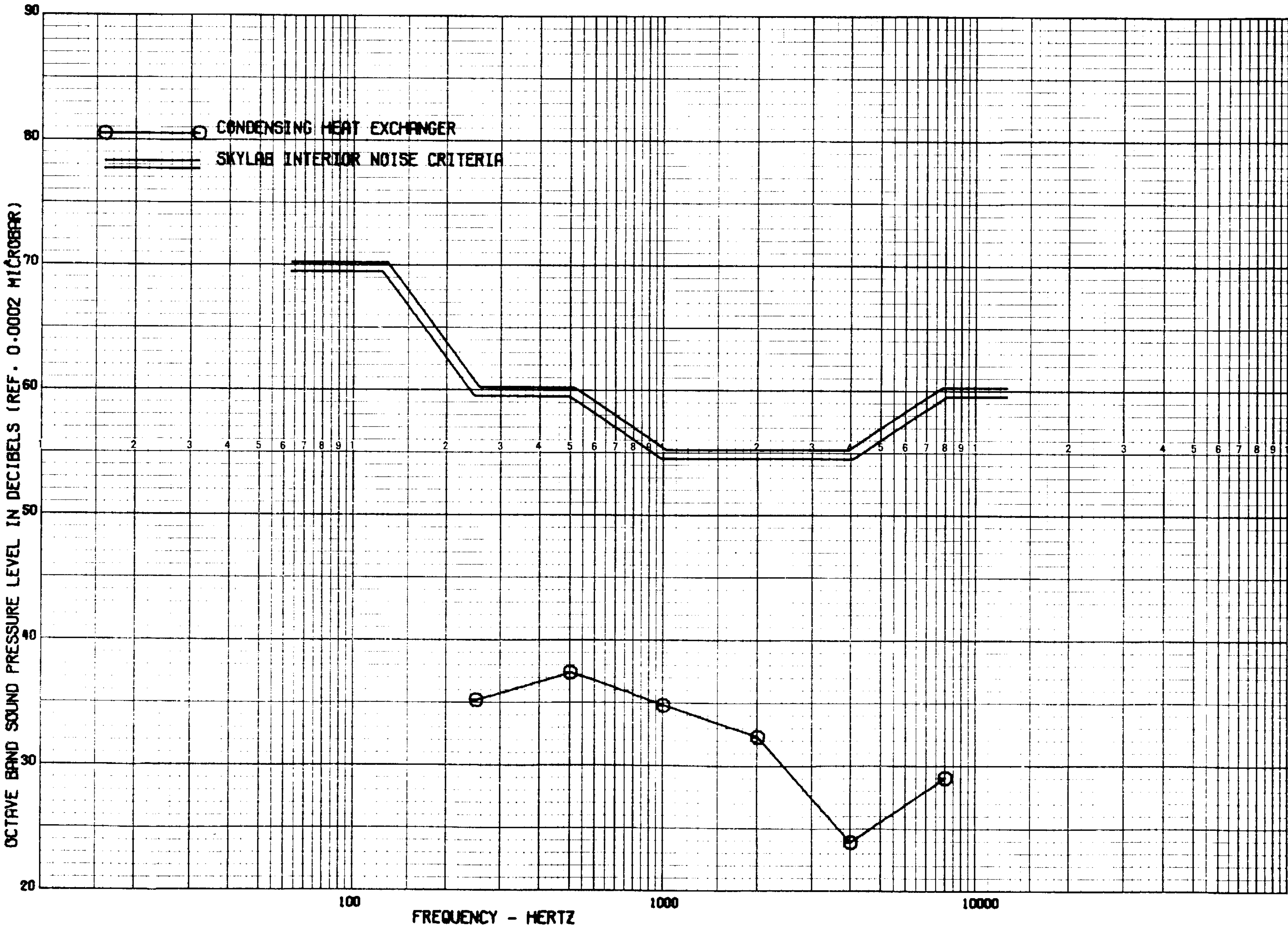

FIGURE 21. ESTIMATED OCTAVE BAND SOUND PRESSURE LEVEL IN OWS DUE TO CONDENSING HEAT EXCHANGER AT 5.0 PSIA

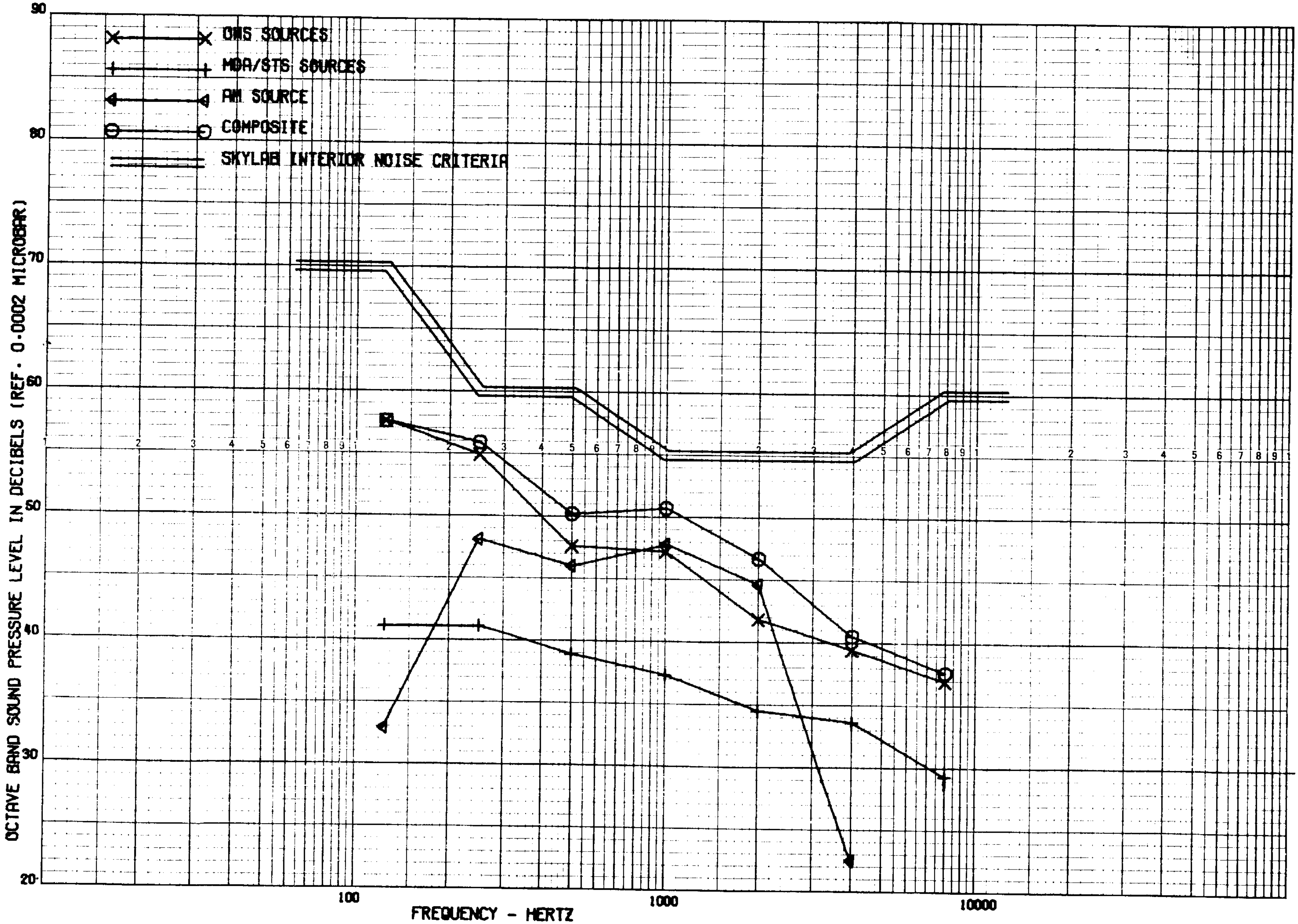

FIGURE 22. ESTIMATED COMPOSITE OCTAVE BAND SOUND PRESSURE LEVEL IN OWS DUE TO CONTINUOUS NOISE SOURCES AT 5.0 PSIA

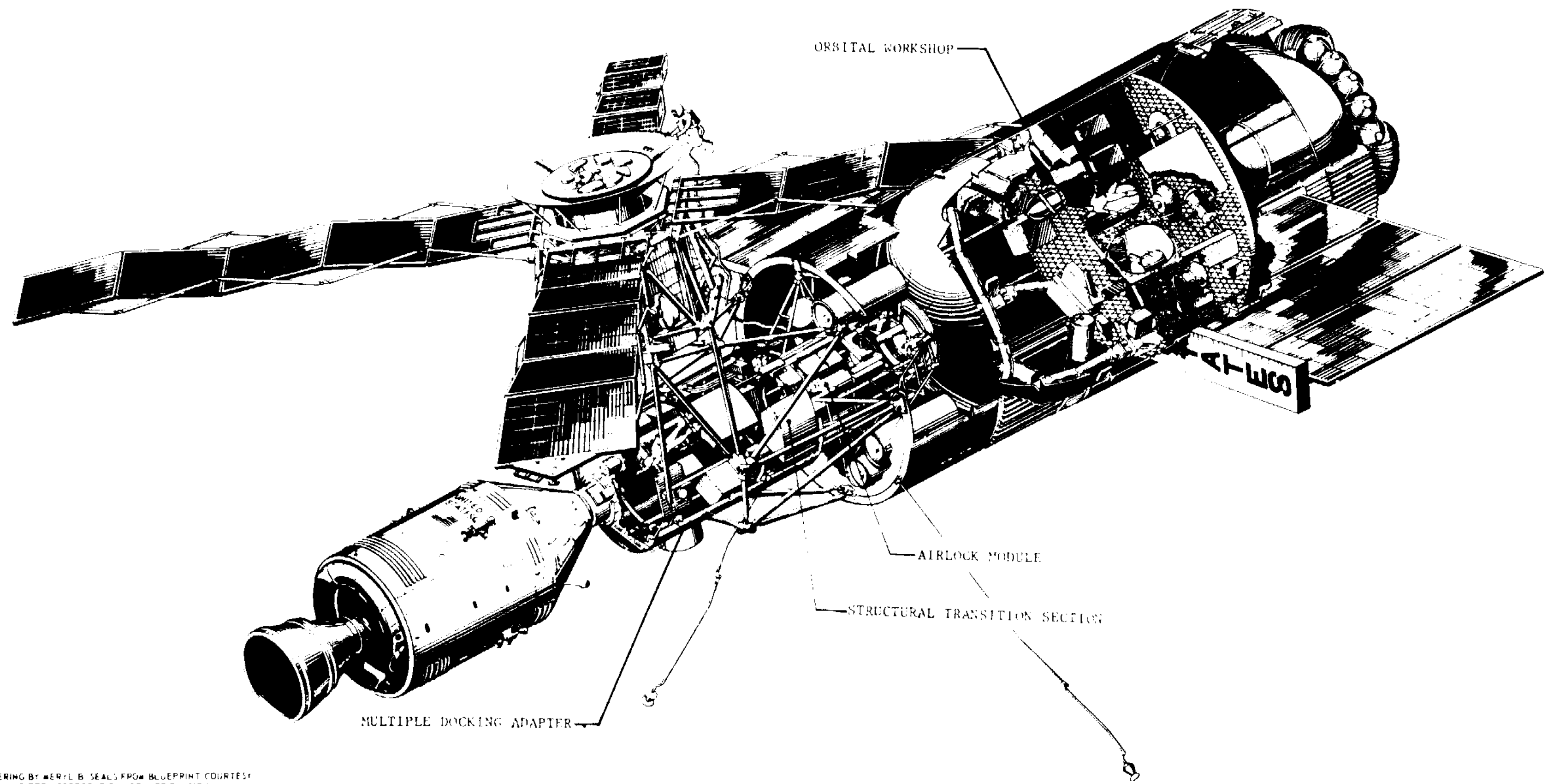

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Figure 23. Skylab Orbital Configuration.

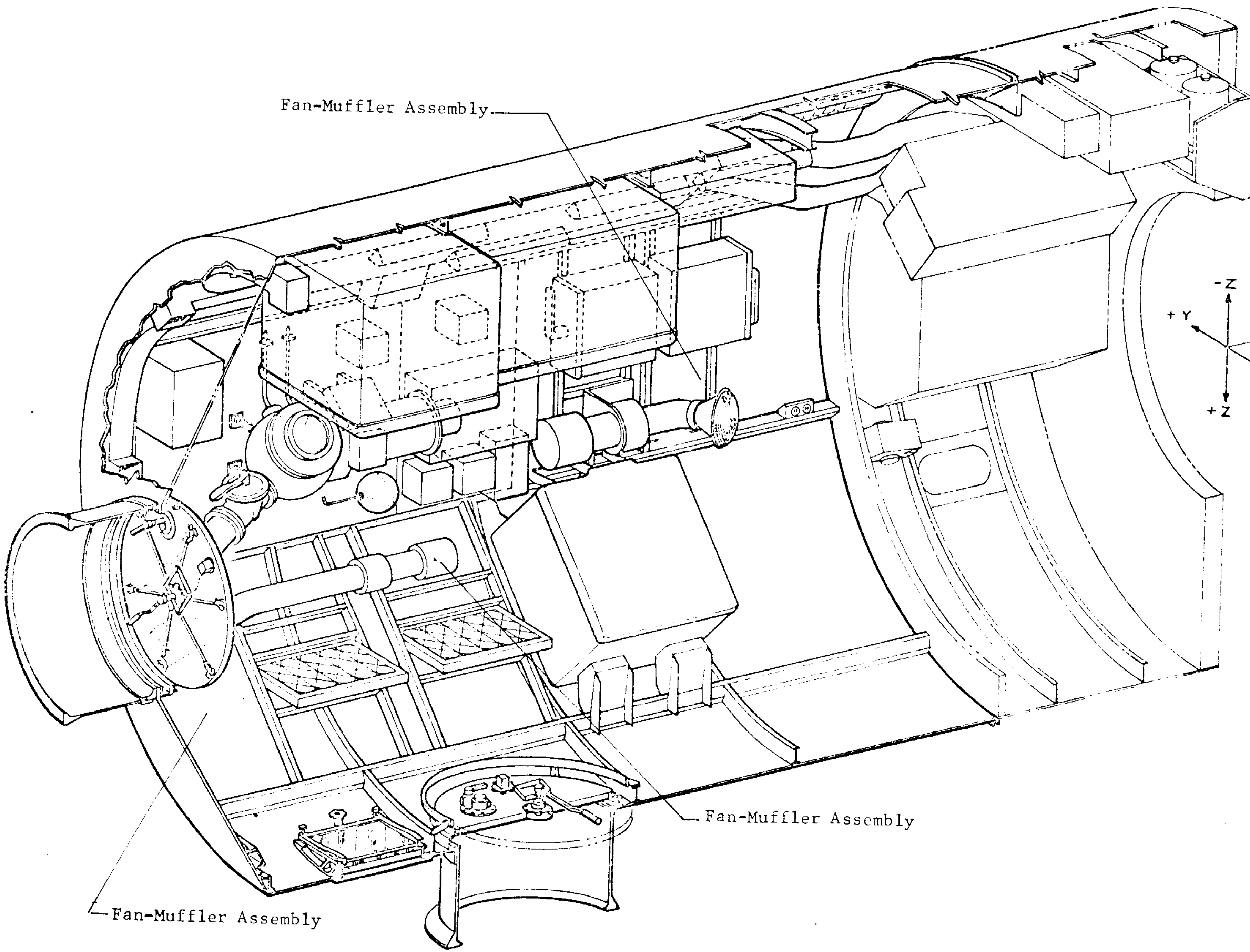


Figure 24 . Location of MDA Noise Sources

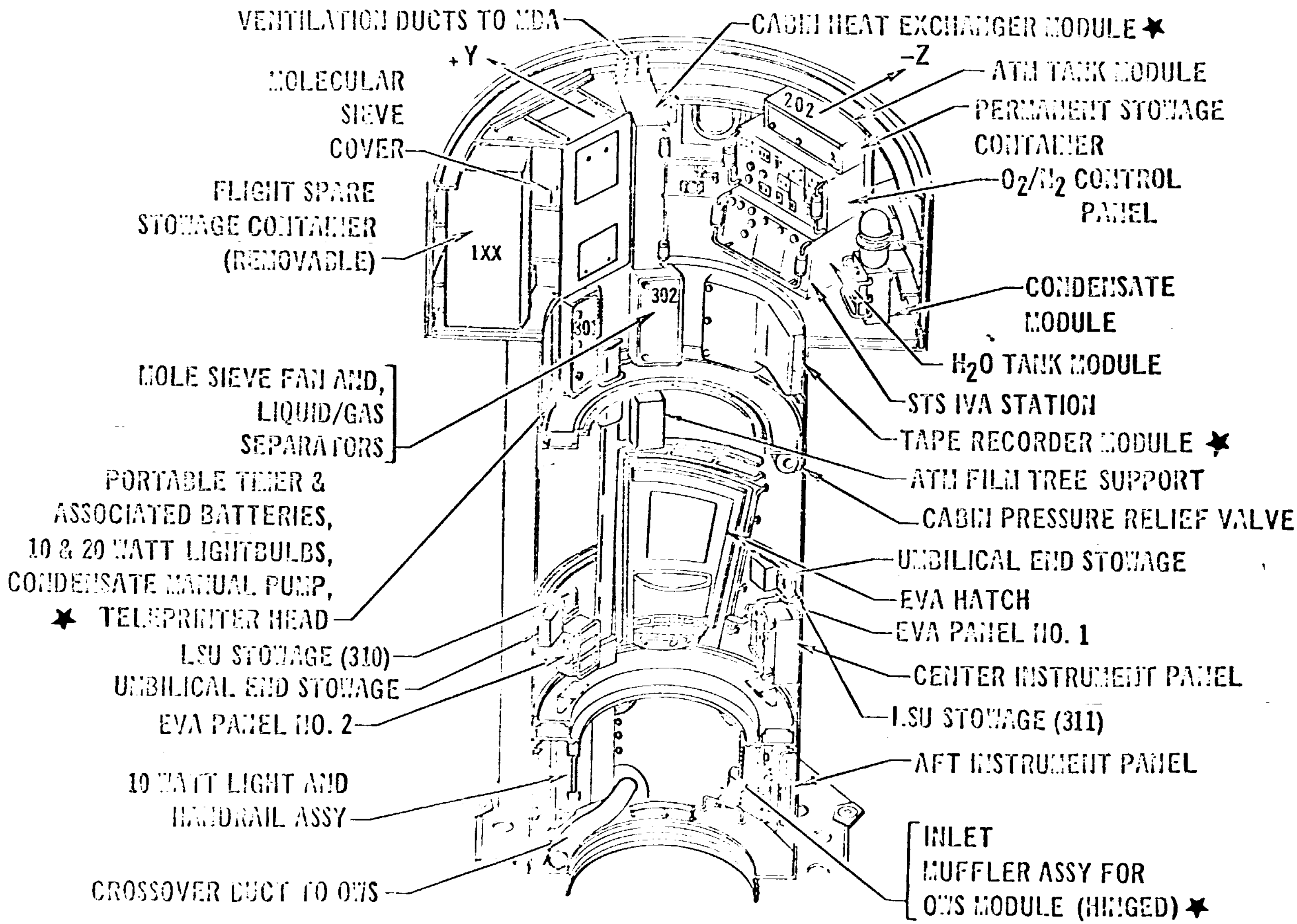


Figure 25. Location of AM/STS Noise Sources

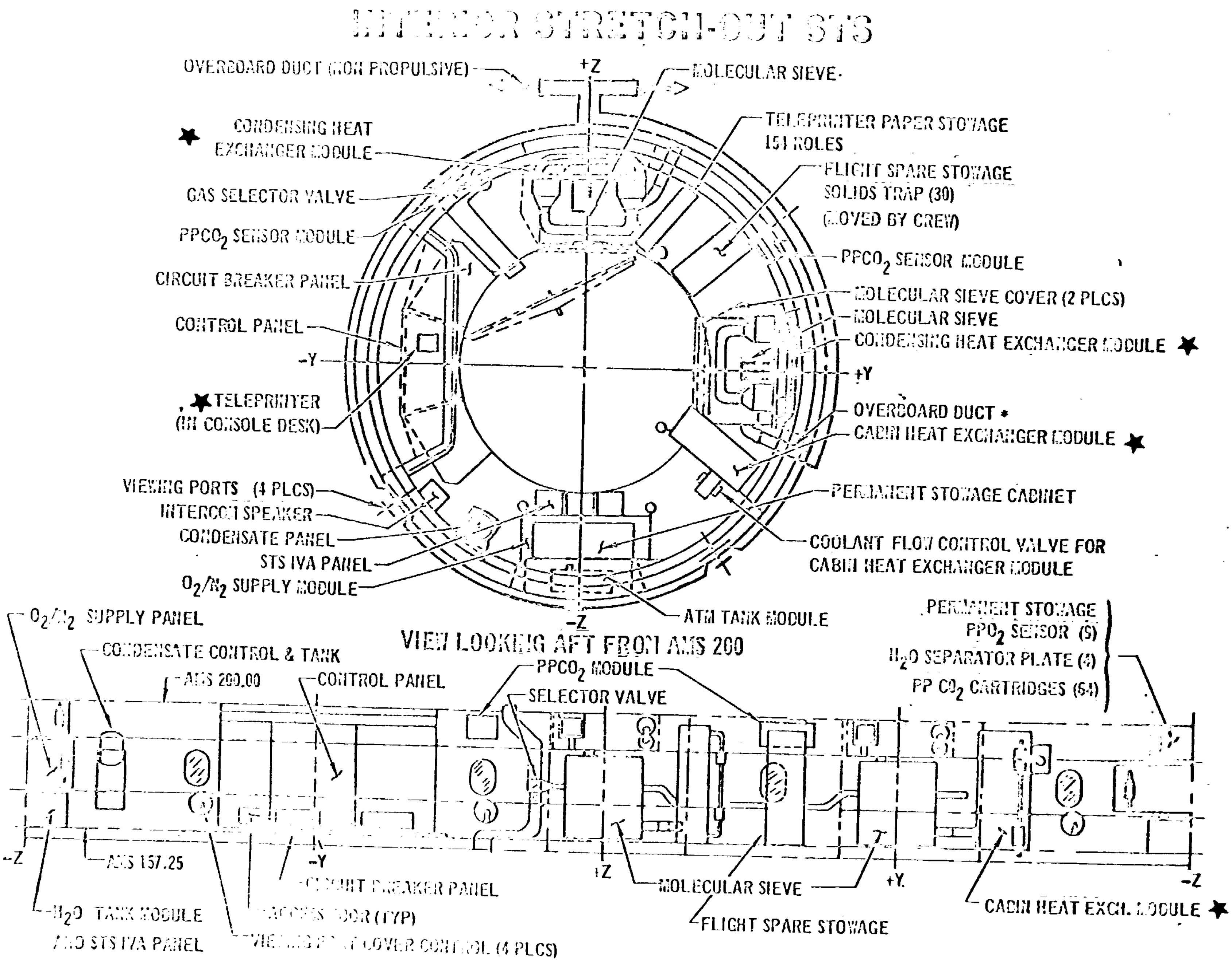


Figure 26. Location of AM/STS Noise Sources

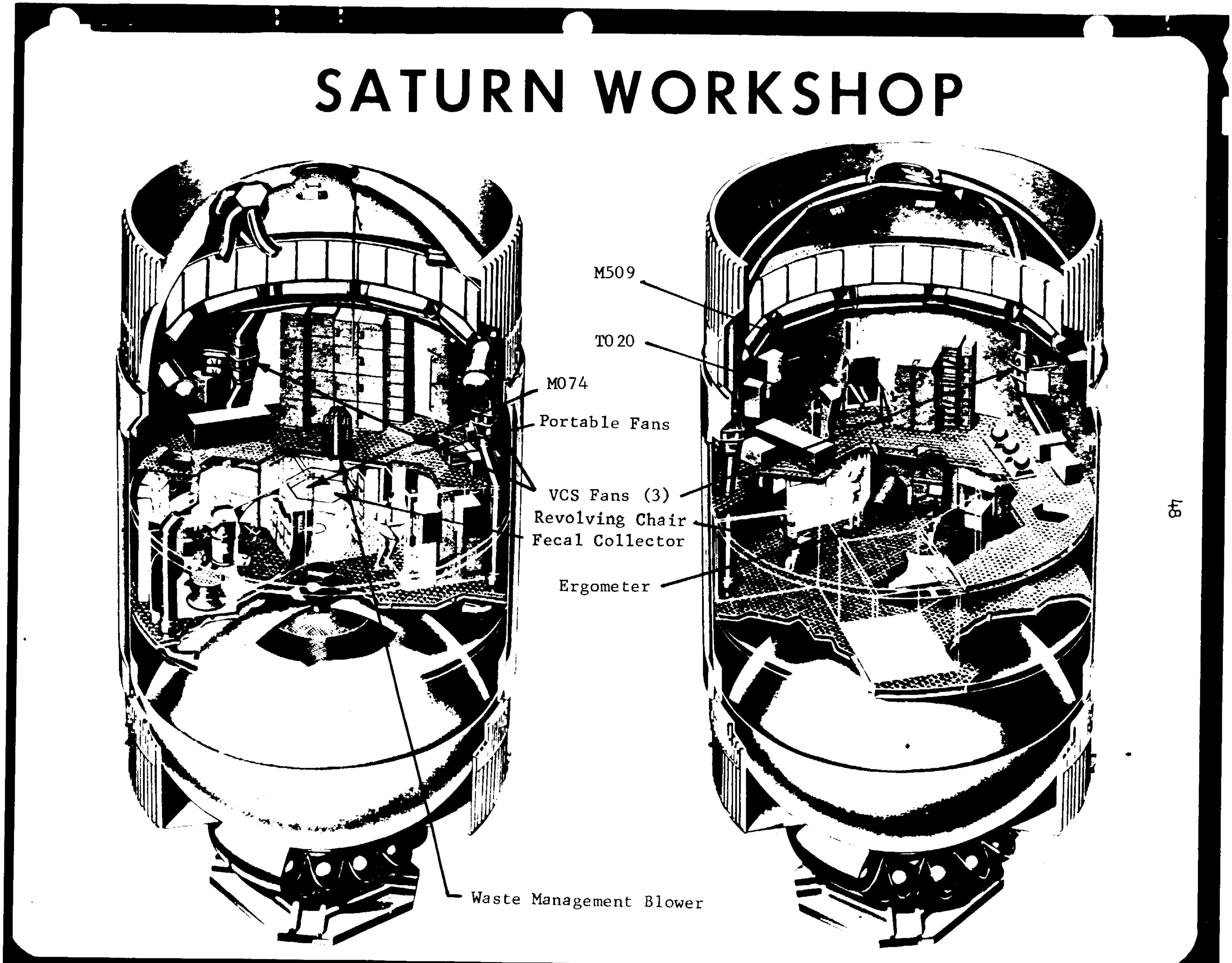


Figure 27. Location of OWS Noise Sources

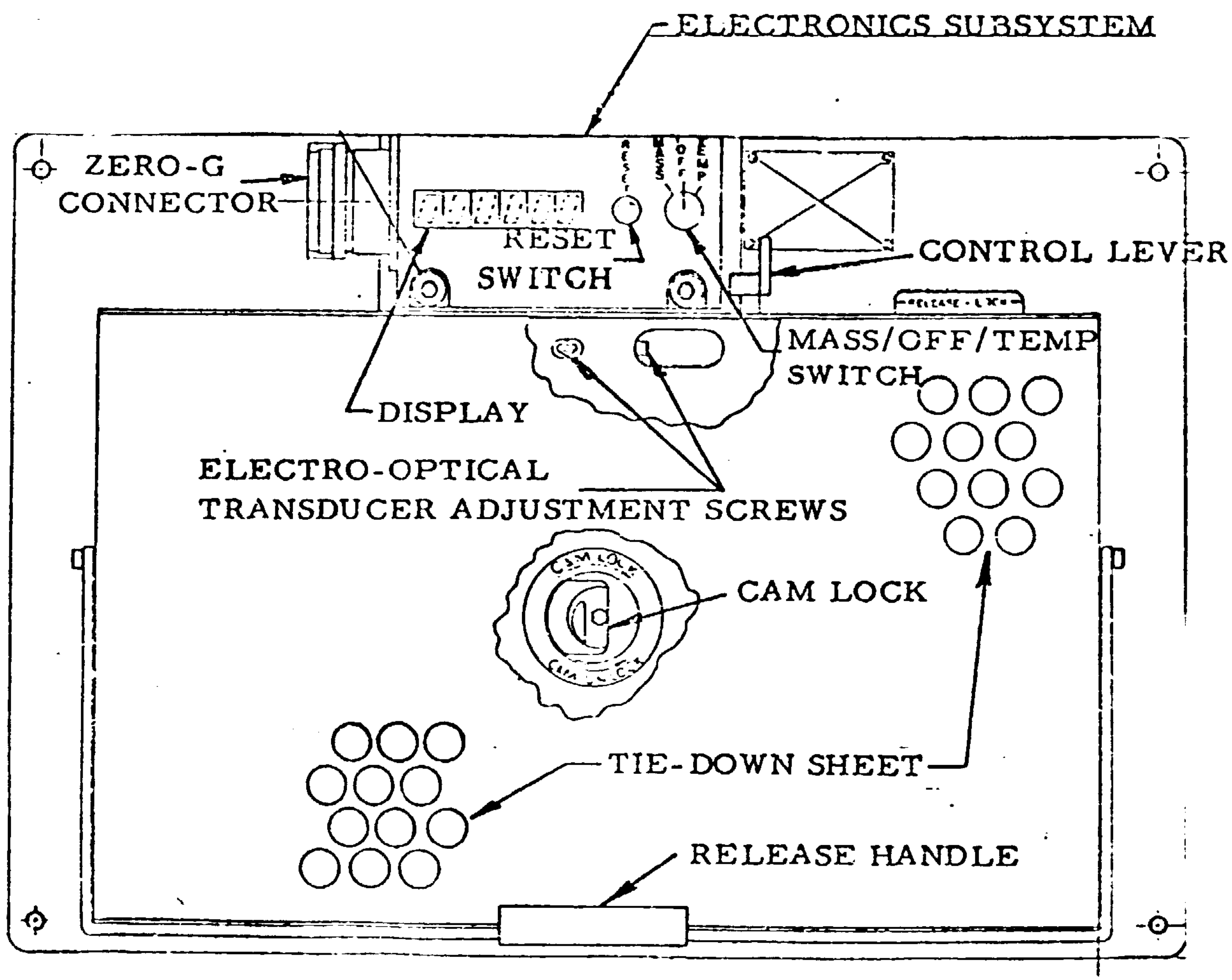
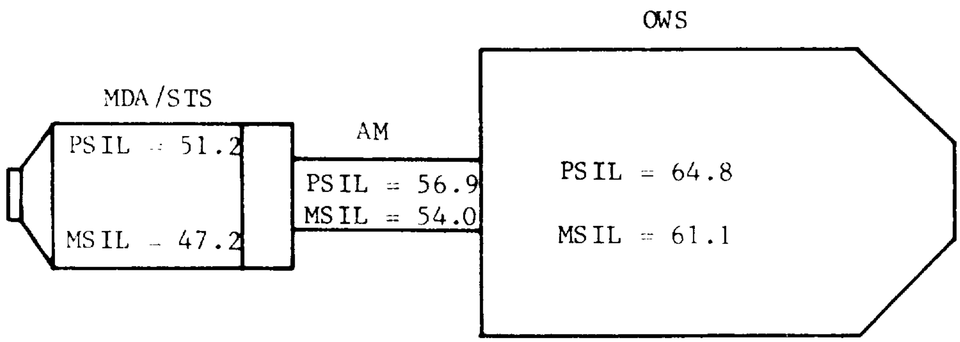
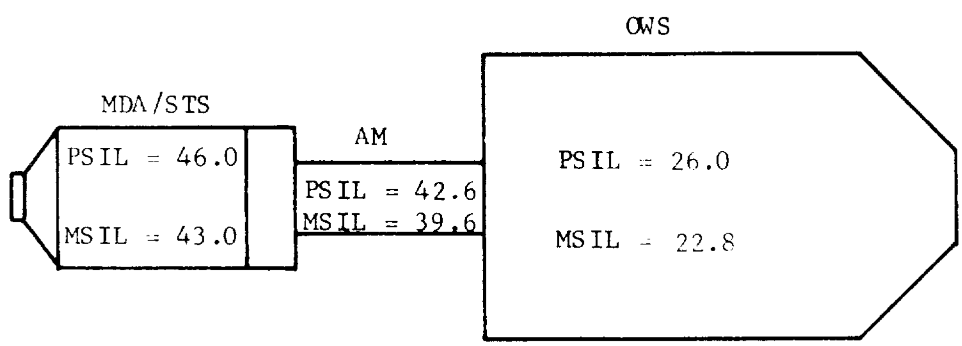


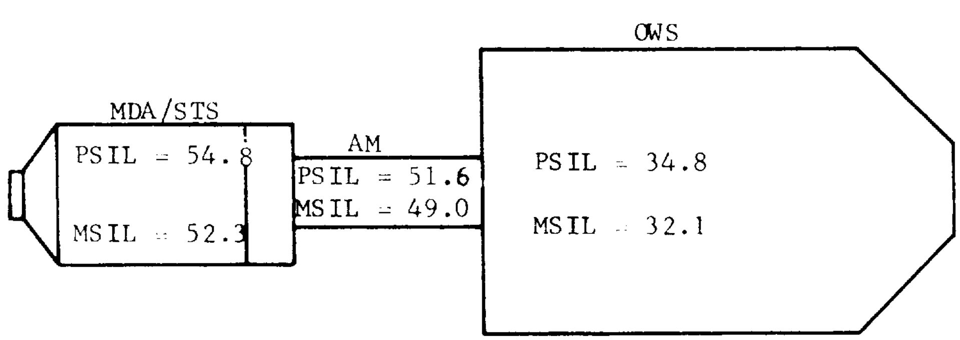
Figure 28. Specimen Mass Measurement Device



a. Ergometer Located in OWS

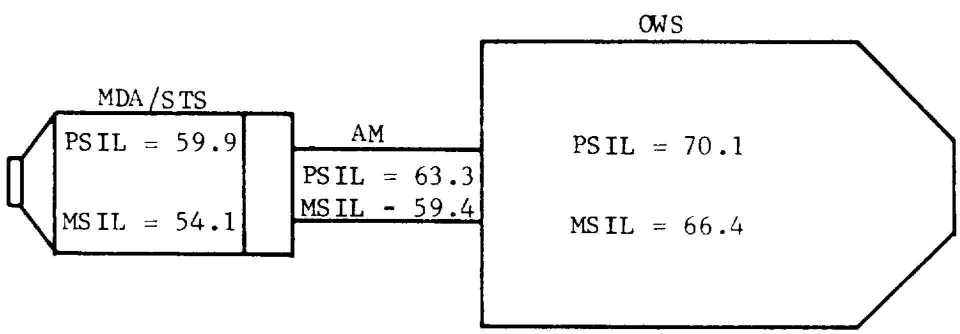


b. OWS Interconnect Duct Fan Located in MDA/STS



c. Condensing Heat Exchanger Located in MDA/STS.

Figure 29. Speech Interference Levels Due to Individual Noise Sources at 5.0 Psia.



Ergometer Located in OWS

Figure 30. Speech Interference Levels Due to Ergometer at 14.7 Psia.

Table I. AM/STS Power Levels at 5.0 Psia Ambient Pressure

OCTAVE BAND FREQUENCY (HERTZ)	INTERCONNECT DUCT FAN PWL (dB)		CONDENSING HEAT EXCHANGER PWL (dB); 12.1 VOLT MODE	
	ORIGINAL	EXPERIMENTAL	ORIGINAL	EXPERIMENTAL
125	54.2	49.9	-----	-----
250	59.6	60.35	74.1	70.4
500	63.3	65.7	72.5	76.1
1000	69.2	66.4	75.0	73.0
2000	63.5	62.1	78.4	71.5
4000	55.5	53.8	82.8	64.0
8000	50.4	53.8	88.4	69.7

Table II. Ergometer Power Levels at 14.7 Psia Ambient Pressure

OCTAVE BAND FREQUENCY (HERTZ)	REVISED PWL (DB)	ORIGINAL PWL (dB)
125	86.3	90.7
250	92.6	97.0
500	93.4	97.6
1000	93.1	96.5
2000	82.6	86.0
4000	75.1	78.3
8000	69.4	73.5

NOTE: Revised PWL's Include Both Direct and Reverberant Energy Effects.
Original PWL's Do Not Include Direct Energy Effects.

Table III. Skylab Equipment and Experiment List

A. Command & Service Module

1. SPS Engine
2. Running Lights (8 places)
3. Scimitar Antenna
4. Docking Light
5. Pitch Control Engines
6. Crew Hatch
7. Pitch Control Engines
8. Rendezvous Window
9. EVA Hand Holds
10. EVA Light
11. Side Window
12. Roll Engines (2 places)
13. EPS Radiator Panels (6 places)
14. SM RCS Module (4 places)
15. ECS Radiator

B. Multiple Docking Adapter

1. Docking Target
2. Experiment M512 Facility
3. ECS Duct to Port 5
4. Vacuum Vent Panel
5. Frame Electrical Umbilical
6. Spare Fan Container
7. Spare Light Container
8. Film Vault No. 1
9. ECS Duct
10. Experiment S082A Cannister
11. Flight Data File
12. Speaker Intercom
13. ATM C&D Console
14. Film Vault No. 4
15. Film Vault No. 3
16. Experiment S009 Support Structure
17. DA Truss Motor (AM)
18. Area Fan (2 places)
19. Film Vault No. 2
20. DA Structure (AM)
21. CO_2 Absorbers and Shims
22. Docking Port No. 3
23. Experiment S065
24. Experiment S101 Resupply
25. Experiment S101
26. Running Light (4 places)
27. External Duct
28. Vacuum Vent Connection for Experiment M512

C. Airlock Module

1. Windows (4 places)
2. Molecular Sieves (2 places)
3. Discone Antennas (2 places)
4. Thermal Blanket
5. O_2 Tanks (6 places)
6. Cabin Press. Relief Valve
7. Suit Storage
8. Bio-Med Cable
9. Suit Storage
10. Undefined Storage Vol.
11. Camera Equip. Storage
12. STS C&D Panel
13. 70MM Film Storage
14. Forward Airlock Hatch
15. Tape Recorder
16. Spare Pressure Control Unit
17. EVA/IVA Umbilicals
18. AFT Compartment Control Panel
19. Heat Exchangers
20. Light Assy.
21. AFT Airlock Hatch
22. Lock Compartment EVA Panels
23. Running Lights (4 places)
24. N_2 Tanks (5 places)
25. EVA/IVA Umbilicals
26. O_2/N_2 Panel
27. Suit Cooling Module
28. Permanent Storage

D. Instrument Unit

None

E. Orbital Workshop

1. OWS Hatch
2. VCS Mixing Chamber & Filter
3. VCS Duct
4. Storage Lockers
5. VCS Duct
6. Thermal Shield
7. O_2 Press. Supply Line
8. Meteoroid Shield
9. Water Containers (10 places)
10. Food Storage (2 places)
11. Storage Lockers
12. O_2 Press. Regulators for H_2O Supply
13. Sleep Restraints
14. Intercom Box
15. Storage Lockers Front & Back
16. Sleep Restraint
17. Sleep Restraint
18. Experiment M131 Equip. Stowage Container
19. Storage Locker
20. Privacy Curtain
21. Experiment M131 Rotating Chair Control Console
22. Storage Locker
23. Drying Area
24. Trash Disposal Airlock
25. TV Outlet
26. Utility Outlets
27. Food Heater
28. Proposed Window
29. Intercom Box
30. Storage Lockers
31. Solar Array Assy.
32. Storage Cabinets
33. Ion Source Shield
34. Utility Outlet
35. Refrig./Freezer
36. Fire Extinguisher
37. Food, Water Heater & Chiller Table
38. Gravity Work Bench
39. Ergometer
40. Gas Analyzer
41. Intercom Box
42. Helmet Box
43. Experiment Support System
44. Lower Body Negative Press. Device
45. OWS Control & Display Console
46. Intercom Box
47. Rotating Chair
48. VCS Duct
49. Crotch Area
50. Meteoroid Shield
51. Thermal Shield
52. Running Light (4 places)
53. Waste Storage Tank
54. APCS Thrusters
55. Meteoroid Shield
56. Trash Disposal Separation Screen
57. APCS GN_2 Spheres (15 places)
58. Running Light (4 places)
59. Solar Array Panels
60. Acquisition Light
61. Interior Light
62. Food Storage Freezer
63. Limb Motion Sensor Assy. Container
64. Microbiological Specimen Freezer
65. Body Mass Measurement Device
66. Force Measuring Unit
67. Proposed VCS Duct
68. Spares Container
69. Astro Aids Container
70. Interior Lights
71. Scientific Airlock
72. Data System
73. Force Measuring Unit
74. VCS Fan Cluster
75. Food Container
76. Intercom Box
77. Suit Container
78. Emergency Access
79. UV Stellar Astronomy Container
80. N_2 Tanks (3 places)

E. Orbital Workshop (Continued)

81. Force Measuring Unit
82. Interior Lights
83. Main Access
84. Heat Filter Fan
85. Emergency Access
86. Portable Water Bottle
87. Interior Lights
88. VCS Fan Cluster
89. Food Container
90. Food Container
91. Coronagraph Container (Experiment T025)
92. Scientific Airlock
93. UV X-Ray SOL-Photo (Experiment S020)
94. Sample Array System Container
95. Water Microbiological Control Equip.
96. Utility Outlet
97. Photometer System Container (Experiment T027)
98. Foot Controlled Maneuvering Unit (Experiment T020)
99. Automatically Stabilized Maneuvering Unit (Experiment M509)
100. Intercom Box
101. Food Containers
102. Restraints Container (Experiment M508)
103. Work Task Board (Experiment M508)
104. Tools

F. Apollo Telescope Mount

1. Command Antenna
2. Telemetry Antenna
3. ATM Solar Array Wing No. 1
4. ATM Solar Array Wing No. 2
5. ATM Solar Array Wing No. 3
6. Command Antenna
7. ATM Solar Array Wing No. 4
8. Telemetry Antenna
9. Charger Battery Regulator Module (6 places)
10. Control Moment Gyro (3 places)
11. ATM Rack
12. CMG Investor No. 3
13. Canister
14. AS&E Aperture Door (Experiment S054)
15. NRL-A Film Retrieval Door (Experiment S082A)
16. H α-2 Aperture Door
17. NRL-B Aperture Door (Experiment S082B)
18. NRL-B Aperture Door (Experiment S082B)
19. NRL-A Aperture Door (Experiment S082A)
20. HCO-A Aperture Door (Experiment S055A)
21. Fine Sun Sensor Aperture Door
22. Acquisition Sun Sensors
23. H α-1 Aperture Door
24. HAO Aperture Door (Experiment S052)
25. GSFC Aperture Door (Experiment S056)

Table IV . Experiment ERD's Reviewed

EXPERIMENT NUMBER	DESCRIPTION
T020*	Foot Controlled Maneuvering Unit
T003	Inflight Aerosol Analysis
T027	Contamination Measurement
T013	Crew Vehicle Disturbances
T018	Precision Orbital Tracking
M512	Materials Processing in Space
M479	Zero Gravity Flammability
M074*	Specimen Mass Measurements
M131*	Human Vestibular Function
M133*	Sleep Monitoring Experiment
M151	Time and Motion Study
M172*	Body Mass Measurement
M113	Blood Volume and Red Cell Life Span
M111	Cytogenetic Studies of Blood
M112	Man's Immunity - Inviro Aspects
M114	Red Blood Cells
M091	Pre-and Post-Flight LBNP
M071	Mineral Balance
M073	Bioassay of Body Fluids
M093	Vectorcardiogram
M171*	Metabolic Activity
D021	Expandable Airlock Technology
D024	Thermal Control Coatings
S009	Nuclear Emulsion
S019	UV Stellar Astronomy (End Item Spec.)
S063	UV Airglow Horizon Photography
M092*	Inflight LBNP
M509*	Astronaut Maneuvering Equipment
S150	Galactic X-Ray Mapping
S149	Particle Collection
S020	X-Ray/UV Solar Photography
S190	Multispectral Photographic Facility
S191	Infrared Spectrometer
S192	10 Band Multispectral Sources
S193	Microwave Radiometer
T025	Coronagraph Contamination Measurement
ESS	Experiment Support System
EREP	Earth Resources Experiment
EXT TV	External Television
M415	Thermal Control Coatings
M487	Habitability/Crew Quarters
Proton Spec	Proton Spec
S073	Gegenschein/Zodiacal Light
S183	Ultra Violet Panorama
S194	L-Band Radiometer
S195	Earth Terrain Camera
T002	Manual Navigations Sightings

*Experiments Having Identified Noise Sources